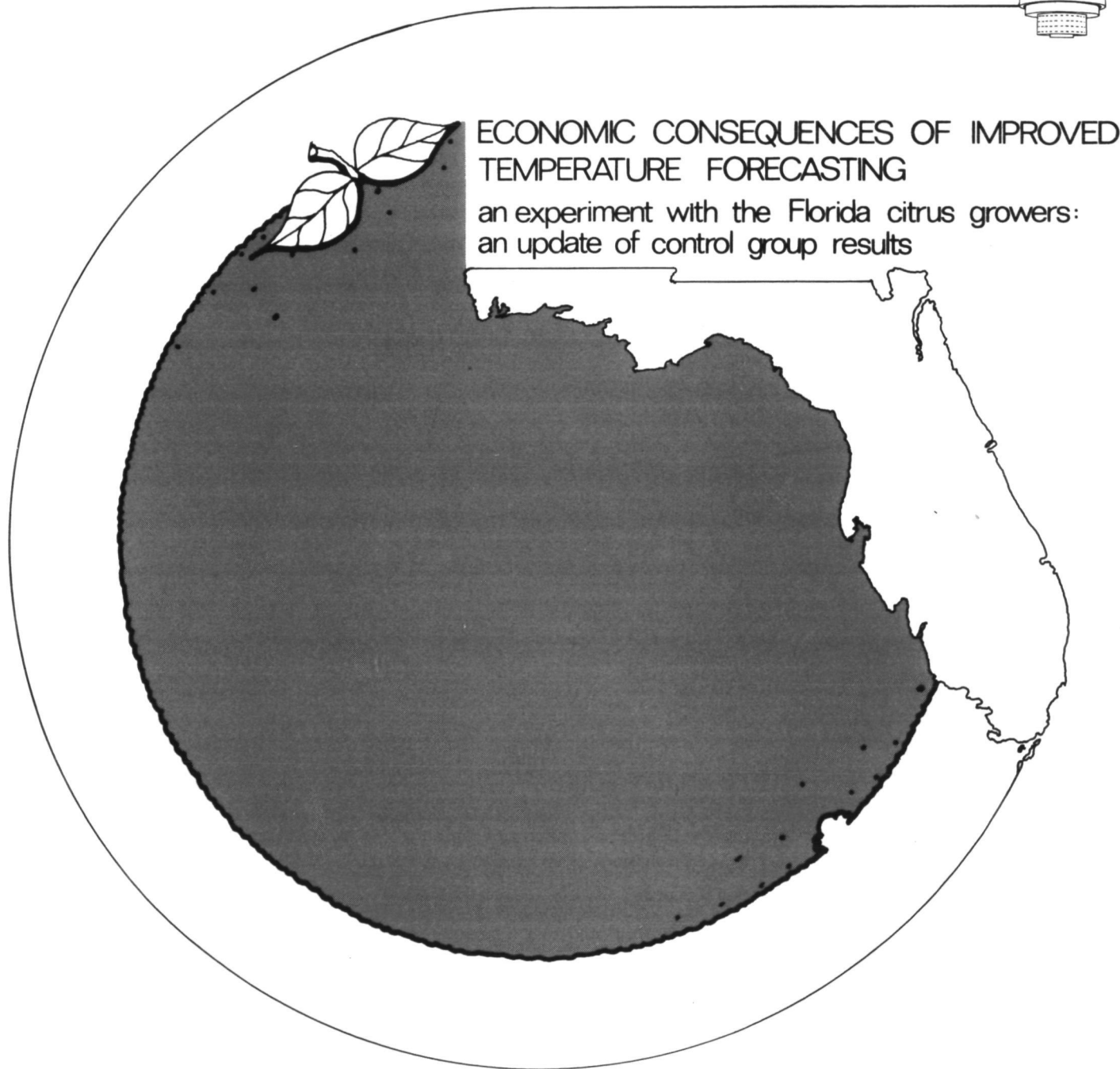


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ECONOMIC CONSEQUENCES OF IMPROVED
TEMPERATURE FORECASTING

an experiment with the Florida citrus growers:
an update of control group results



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ECONOMIC CONSEQUENCES OF IMPROVED
TEMPERATURE FORECASTS: AN EXPERIMENT
WITH THE FLORIDA CITRUS GROWERS
(AN UPDATE OF CONTROL GROUP RESULTS)

Prepared for
National Aeronautics and Space Administration
Office of Applications
Washington, DC

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ABSTRACT

In late 1977 a demonstration experiment was initiated, and is currently in progress, to show that frost and freeze prediction improvements are possible utilizing timely Synchronous Meteorological Satellite (SMS/GOES) temperature measurements and that this information can affect Florida citrus grower operations and decisions so as to significantly reduce the cost for frost and freeze protection and crop losses. As part of this effort, ECON, Inc. designed and conducted the first phase (during the 1976-77 and 1977-78 frost seasons) of an economic experiment which is designed to monitor citrus growers' decisions, actions, costs and losses, and meteorological forecasts and actual weather events. Continued data collection during the 1978-79 frost season will allow the economic benefits of improved temperature forecasts to be established. The economic experiment is designed to measure the change in annual protection costs and crop losses which are the direct result of improved temperature forecasts.

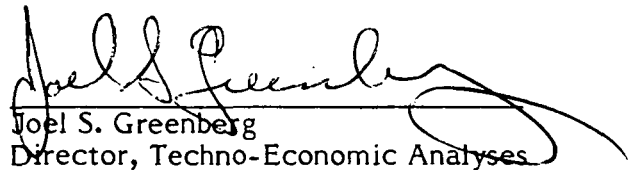
To estimate the benefits that may result from improved temperature forecasting capability, control and test groups have been established with effective separation being accomplished temporally. The economic benefits of the improved forecasting capability will be the difference between normalized costs and losses of these two groups extrapolated across the state of Florida. The control group, utilizing current forecasting capability, was observed during the 1976-77 and 1977-78 frost seasons. The test group, benefiting from improved temperature forecasting capability expected to result from the utilization of SMS/GOES data in combination with forecast models being developed by the University of Florida, will be observed during the 1978-79 frost season. The original intent was to observe the test group during both the 1977-78 and 1978-79 frost seasons. However, delays in achieving the improved forecasting capability precluded the use of the 1977-78 data as representing the test group.

This report presents a summary of the economic experiment, the results obtained to date and the work which still remains to be done. Specifically, the experiment design is described in detail as are the developed data collection methodology and procedures, sampling plan, data reduction techniques, cost and loss models, establishment of frost severity measures, data obtained from citrus growers, National Weather Service and Federal Crop Insurance Corp., resulting protection costs and crop losses for the control group sample, extrapolation of results of control group to the Florida citrus industry and the method for normalization of these results to a normal or average frost season so that results may be compared with anticipated similar results from test group measurements. This report is an update of ECON Report No. 77-261-1 entitled "Economic Consequences of Improved Temperature Forecasts: An Experiment with the Florida Citrus Growers (Control Group Results)" dated November 30, 1977.

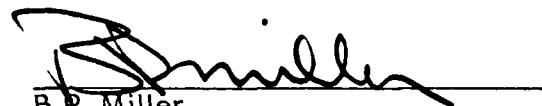
ACKNOWLEDGEMENTS

ECON, Inc. acknowledges the contributions of Chris Braen, Fred Clyne and Keith Lietzke who performed the bulk of the analyses. They, together with Joel S. Greenberg, authored this report. Dr. Francis Sand provided invaluable technical assistance. The economic experiment described in this report could not have been accomplished without the close cooperation of the National Weather Service, Florida County Extension Service, Federal Crop Insurance Corp and the University of Florida. Particular appreciation is extended to the 52 Florida citrus growers who provided the crop protection and damage data which is the very essence of this experiment, and John Jackson, Tom Oswalt, Ed Richards, Jack Hayman, Bill Phillips and Tim Hurner, the county extension agents, who played a key role in the overall data-gathering process. Credit is also due to Marilyn Molnar and Linda Oswalt who played a major role in the data collection process.

The reported experiment was under the technical direction of Mr. Ernest Neil at NASA's Goddard Space Flight Center.



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1. EXPERIMENT OVERVIEW

1.1 Introduction

In late 1977 a demonstration experiment was initiated, and is currently in progress, to show that frost and freeze prediction improvements are possible utilizing timely Synchronous Meteorological Satellite (SMS/GOES) temperature measurements and that this information can affect Florida citrus grower operations and decisions so as to significantly reduce the cost for frost and freeze protection and crop losses. As part of this effort, ECON, Inc. designed and conducted the first phase (during the 1976-77 and 1977-78 frost seasons) of an economic experiment which is designed to monitor citrus growers decisions, actions, costs and losses, and meteorological forecasts and actual weather events. Continued data collection during the 1978-79 frost season will allow the economic benefits of improved temperature forecasts to be established. The economic experiment* is designed to measure the change in annual protection costs and crop losses which are the direct result of improved temperature forecasts. This report describes the experiment and the results obtained to date. It should be noted that the reported economic experiment must, of necessity, encompass data collection during several frost seasons. Data collection must occur during one or more frost seasons prior to as well as after the introduction of the improved forecasting capability (the control and test groups, respectively). The original intent was to observe the control group during the 1977-78 frost season and the test group during the 1977-78 and 1978-79 frost seasons. However, delays in achieving the improved forecasting capability

* Described in "A Plan for Application System Verification Test--The Value of Improved Meteorological Information," ECON, Inc. Report No. 76-108-2, August 31, 1976, prepared under NASA Contract No. NASW-2558.

precluded the use of the 1977-78 data as representing the test group. It appears that the weather forecast accuracy during both the 1976-77 and 1977-78 frost seasons is consistent (even though some satellite data was available to the NWS forecasters during the latter frost season) whereas there appear to be some inconsistencies in the cost data from the two seasons. Additional analysis is necessary to try to remove these inconsistencies so that the data from both seasons may be used to encompass the control group data base. This is discussed in following sections. Since only control group data has been obtained to date, no conclusions can yet be drawn relative to the magnitude of the economic benefits which may result from improved temperature forecasts provided to the Florida citrus growers.

This report is an update of ECON Report No. 77-261-1 entitled "Economic Consequences of Improved Temperature Forecasts: An Experiment with the Florida Citrus Growers (Control Group Results)" dated November 30, 1977.

In order to estimate the benefits that may be realized by the citrus growers as a result of improved temperature forecasting capability, control and test groups have been established. Effective separation between the two groups of sample growers is accomplished temporally. The control group, utilizing current forecasting capability, was observed during the 1976-77 and 1977-78 frost seasons. The test group, benefiting from the improved temperature forecasting capability that will result from the utilization of SMS/GOES data in combination with forecast models being developed by the University of Florida, will be observed during the 1978-79 frost season. The economic benefits of the improved forecasting capability will then be the difference between the normalized costs and losses of these two groups extrapolated across the state of Florida.

During the previous year's activity, the details of the experiment design* were developed, data collection methodology and procedures were determined, control group data collection was undertaken and completed, data reduction techniques developed and implemented, and economic analyses undertaken. The previous year's work also resulted in the development of the experiment sampling plan, the methodology for establishing protection costs and losses resulting from inadequate protection in terms of temperature forecasting capability, and the development of the means for collecting data which would demonstrate the economic (and fuel conservation) consequences of improved temperature forecasting.

ECON established a sampling plan concerned with the determination of the specific growers (and groves) who would participate in the conduct of the experiment. Specific grower selection considered the desired number of samples to be included in the test and control group. This included consideration of the accuracy of the data and the segmentation requirements (in terms of geographic location, frost protection practices, soil types, citrus crop types, etc.). A major consideration was County Extension Service experience with growers and the population of growers which was expected to be cooperative. The sampling plan concept was developed and reviewed with the county extension agents and resulted in a selection of growers who would participate in the experiment. After completion of the determination of grower data requirements and data forms, discussions were held with the growers to make a final determination of which growers would participate in the experiment. As part of this initial effort the

* Particular attention and care has been devoted to the design of an experiment which allows temporal separation of control and test groups and which will provide valid results even though there may be significant differences between the weather events encountered during the control and test group frost seasons.

specific procedures for data gathering were determined, including the roles of the National Weather Service, the County Extension Service, the University of Florida, the Federal Crop Insurance Corporation and the citrus growers.

Preliminary cost and loss determination methodologies were determined and detailed citrus grower and National Weather Service data requirements were determined. These data requirements were reviewed with the County Extension Service and National Weather Service. The result was the determination of the specific data needs matched with the availability of data from the growers and the National Weather Service. Finally, data forms were developed which placed major emphasis upon minimizing the data collection burden on the grower. Three data forms were developed: one to gather data which may be considered as invariant during the frost season; one to gather data on the daily protection costs, events, decisions and actions; and one to gather data on fruit and tree damage. These forms were filled out for each of the groves in the sample. As a result of the 1976-77 data collection, the data forms were modified so as to increase the efficiency of data collection during the 1977-78 and following frost seasons. Sources were also developed and data obtained for citrus spot and future prices, and fuel prices.

Cost and loss determination methodologies have been developed and result in the determination of the average cost and loss per frost event per grove. The methodology allows a "normal" or average frost season to be defined in terms of number of days of different levels of frost severity at each grove. Normalized annual costs and losses for both the control and test groups are to be established, the difference between these costs and losses will be the annual benefit of the improved forecasts to the citrus growers comprising the sample. Procedures have also been developed for extrapolating these results across the Florida citrus

industry, taking into account such factors as citrus type, grove location, frost protection practices, frost occurrences and Federal Crop Insurance Corporation indices.

Methods and procedures have been developed for establishing a frost severity index based upon the duration of different levels of frost and its impact (damage) on fruit and trees. This requires knowledge of the grove temperature (as a function of time) that would have occurred in the grove if protective action were not taken. To accomplish this, methods were devised for relating National Weather Service control thermometer thermographs to grove temperature (for each grove in the data base) which are then used to establish the grove frost severity index for each night of frost.

The developed data collection procedures were implemented for a control group consisting initially (1976-77 frost season) of 245 groves operated by 52 growers. By the end of the second year of data collection, the control group consisted of 199 groves operated by 39 growers.* During the next year of data collection an attempt will be made to increase this group. With the assistance of the county extension agents, Grove Background Reports were obtained for the 245 groves. Approximately 2150 Nightly Frost/Freeze Protection Activity Reports and several hundred Damage Reports were obtained for the 1976-77 frost season. Additionally 2884 Nightly Frost/Freeze Activity Reports and 45 Damage Reports** were obtained for the 1977-78 frost season. Additional data was provided by the

* Groves and growers were considered to have "dropped-out" from the experiment if the grower explicitly stated this or if insufficient data was received indicating lack of continued interest.

** The number of damage reports for the 1977-78 frost season is significantly less than that of the previous year because of modified data collection procedures and because of a generally milder winter.

Florida Crop and Livestock Reporting Service and the Federal Crop Insurance Corporation. The NWS provided all necessary weather forecasts and control thermometer thermographs. In addition, the NWS provided detailed temperature records of the past 30 years so that a "normal" or average year can be ascertained for control and test group comparisons.

The collected data forms were reviewed, and data was transformed and entered into a computerized data base. This data base (of the control group) is utilized in the determination of events and average annual costs and losses. Daily costs and losses have been established for each grove and classified by event type, citrus grower type, and frost severity. Average costs and losses have been determined and annual costs and losses established for this control group. The developed capability, with suitable modifications to take into account price variations between control and test group years, will allow the results of the control and test groups to be compared and the annual demonstrated benefits to be established. These benefits, based upon the sample population, will be extrapolated to total Florida citrus industry annual benefits, taking into account grower geographic locations, geographic temperature patterns, grower crop protection capabilities and crop type. The net result will be the establishment of demonstrated benefits and extrapolated (from the measured benefits) benefits which are the direct result of improved frost protection decisions made possible by improved temperature forecasting capability.

To summarize, the experiment for measuring the economic value of improved temperature forecasts to the Florida citrus growers has been designed, data requirements and data collection methods and procedures have been determined, and control group data collection completed. The data has been entered into a computer data base. The methodology for establishing annual costs and losses has

been established and control group analyses nearly completed. Some analyses are still required with respect to the comparison of the two control group years with the intent of being able to merge the data into a single control group. Control group results have been extrapolated to all applicable protected citrus acreage in Florida. It is this economic value (protection costs plus economic crop losses) which is to be compared with similar data to be obtained from the experiment test group. Test group data will be obtained during the 1978-79 frost season.

The remainder of this report is concerned with a description of the economic experiment, the results obtained to date, and the work which still remains to be done (i.e., test group data collection and analysis and comparison of control and test group results). Sections 1.1 and 1.2 present an overview of the experiment and a summary of the experiment (control group) results obtained to date, respectively. The following sections present the pertinent details of the experiment. Section 2 describes the general value of frost forecasts to the Florida citrus industry and includes the geographical distribution and production values of citrus-producing regions, the weather sensitivity of citrus, the role of the National Weather Service (NWS), and citrus grower frost protection methods and decision processes.

Section 3 is concerned with the design of the experiment, including the concept, methodology, measurement and data collection techniques. This includes the concept of establishing control and test groups, the sampling plan, extrapolation from the sample to the Florida citrus industry and normalization of results to a standard weather pattern. Also described are the grower data collection forms and techniques; the NWS data including control thermometer thermographs, weather forecasts and minimum temperature records; and the methods used to establish citrus grove temperature profiles, frost/freezing severity measures, and the susceptibility of groves to frost/freezing damage.

Section 4 is concerned with forecast verification, a statistical analysis of forecast errors where a forecast error is defined to be the difference between the forecasted and actual temperature at a particular location. The forecast verification was performed for each of the control years and the results compared.

Section 5 presents an analysis of costs and losses, including the cost model and loss model (fruit losses and tree losses). Also discussed is the expansion of costs and losses from the experiment sample to the Florida citrus industry and the normalization of costs and losses to a standard weather pattern. Section 6 presents an assessment of the control group results and includes additional control group experiment results (1976-77 and 1977-78 frost seasons). Section 7 presents the tasks and schedules for completing the test group data collection and performing the analysis and comparison of the control and test group results.

1.2 The Economic Experiment

The citrus grower, upon receipt of a forecast for temperatures below approximately 28°F, must decide whether or not to protect his crop. Normal protective measures (see Section 2.5) include the firing of diesel heaters or the use of electrically operated wind machines. Decisions must be made with respect to when to call in crews, when to turn heaters and/or wind machines on and off and how many heaters to utilize. These decisions affect citrus crop protection costs and losses resulting from inadequate protection measures. The purpose of the economic experiment is to determine the magnitude of the benefits which may result from improved temperature forecasts to the citrus growers. The benefits may result from cost reductions, loss reductions and improved marketing decisions which may be the result of improved knowledge of previous nights' temperature distribution across the state. This latter benefit area, though possibly large, is not considered in the current experiment and will not be discussed further. Cost

reductions will result from improved scheduling of crews due to false alarms (forecast for temperatures which would normally require the initiation of protective measures but, in actuality, the potentially damaging temperatures do not occur) reductions and improved timing of the initiation and termination of protective measures. Loss reductions will result from improved scheduling of crews due to probability of miss (the likelihood of forecasting temperatures for which protective action is not required when, in actuality, temperatures occur at which protective action is required) reduction and improved timing of the initiation and termination of protective measures.

Table 1.1 illustrates, through the use of a hypothetical though typical example, the costs and losses which may result from a grower's protection decision and actual freeze severity given a freeze forecast for minimum temperatures less than 28°F. Two situations are shown and compared, namely, (a) the grower's decision was not to protect, and (b) the grower's decision was to protect. In each case the results are illustrated, given that no freeze developed, a moderate freeze developed and a severe freeze developed. Indicated in the table are the cost of protection, the price before the freeze, the price after the freeze (this price is a function of the freeze severity since it is assumed that, independent of the specific grower protection decision, damage will be inflicted by the freeze on other groves throughout the state of Florida and will, therefore, affect supply which in turn affects price), the expected yields before and after the freeze and resultant physical losses.

It should be noted that protection cost is a function of the protection decision and the severity of the freeze. It should also be noted that the yield expected after the freeze is a function of both the protective decision and the severity of the freeze. The effect of the grower's protection decision and severity of freeze is

Table 1.1 An Illustrative Example of Costs and Losses In Terms of Grower's Protection Decisions and Freeze Severity*

	No Protection			Protection		
	No Freeze	Moderate Freeze	Severe Freeze	No Freeze	Moderate Freeze	Severe Freeze
Cost of Protection (\$/Acre)	0	0	0	3.26	15.85	67.52
Price Before Freeze (\$/Box)	2.50	2.50	2.50	2.50	2.50	2.50
Price After Freeze (\$/Box)	<u>2.50</u>	<u>3.00</u>	<u>3.25</u>	<u>2.50</u>	<u>3.00</u>	<u>3.25</u>
Change in Price Due to Freeze (\$/Box)	0	0.50	0.75	0	0.50	0.75
Yield Expected Before Freeze (Box/Acre)	350	350	350	350	350	350
Yield Expected After Freeze (Box/Acre)	<u>350</u>	<u>170</u>	<u>50</u>	<u>350</u>	<u>330</u>	<u>300</u>
Physical Losses (Box/Acre)	0	180	300	0	20	50
Revenue Gains or Losses** (\$/Acre)	0	-365	-712.50	0	+115	+100
Economic Gains or Losses+ (\$/Acre)	0	-365	-712.50	-3.26	+99.15	+32.48
Value of Protection to Grower This Night++ (\$/Acre)	--	--	--	-3.26	+464.15	+744.98

* It is assumed that on this night a freeze was forecast with minimum temperature less than 28°F.

** (price before freeze x yield expected before freeze) - (price after freeze x yield expected after freeze).

+ revenue change due to protective action less the cost of protection.

++ economic gains or losses with protection less the economic gains or losses without protection.

thus seen in terms of cost of protection and physical losses (boxes/acre). The grower may be better or worse off, depending upon the combination of the change in price due to the freeze and the effectiveness of grower protective action. This is shown as the revenue gains or losses (\$/acre) and may range from a large loss (\$712.50/acre when no protection is undertaken and a severe freeze occurs) to a large gain (\$100/acre when effective action is taken and a severe freeze occurs). The economic gains or losses to the particular grower are thus the revenue gains or losses less the cost of protection.

The value of protective action to the grower for the specific case illustrated in Table 1.1 is the difference between the economic gains or losses with and without protective action for the same level of frost severity. It should be noted that this example did not take into account the likelihood of freeze severity given a specific temperature forecast. This is an important factor which temporizes the numbers illustrated in Table 1.1 and is taken into account in the development of experiment results.

It has been estimated that as much as \$5 million is spent on frost protection measures by the Florida citrus growers on a severe frost night. In light of the continuing increase in diesel and gasoline prices, this nightly cost may rise dramatically in the near future or losses from lack of protection may increase. In the event of tree and fruit damage, the statewide dollar loss may be measured in many millions of dollars, as happened during the winter of 1977. Any possible reduction in both the nightly costs of frost protection and extent of freeze damage will be closely related to the strategy the growers employ once frost has been forecasted. Though many factors influence the grower's initial decision to protect and his nightly strategy, a most important factor is the confidence given to the temperature forecasts. It is felt that the satellite forecast system, now scheduled for operation during the 1978-79 frost season, will better assist the individual grower, not only in his initial protection decision, but more importantly, during the hour-by-hour "wait and watch" period when frequent temperature updates are received.

The Synchronous Meteorological Satellite (SMS/GOES) is currently providing temperature and other meteorological data to ground receiving stations throughout the United States. During the 1978-79 frost season, the National Weather Service Office in Ruskin, Florida will receive SMS/GOES temperature observations of

peninsular Florida and will process this data with the assistance of (1) an image interpreter purchased by NASA and (2) a temperature forecast model developed at the University of Florida. The satellite's ability to frequently observe the entire state with 4-nautical-mile spatial resolution and 0.5-degree centigrade temperature resolution should improve both the accuracy and timeliness of NWS frost forecasts. The observed temperature data and the temperature forecasts will be provided to the NWS forecaster who will then use this data as another important input upon which to base his frost/freeze forecast. During the 1977-78 frost season, this system was partially operational and provided some data on actual observed (SMS/GOES) temperatures.

In order to measure the economic benefits of improved temperature forecasts it is necessary to establish and then compare the nightly costs and losses experienced by growers resulting from (1) using the improved forecasts and (2) using the present forecast system. This methodology implies the establishment of a control group (using present forecasting capability) and a test group (using the SMS/GOES-derived improved forecasts) of representative growers (see Section 3.1). Since the improved forecasts will be freely available to all growers, it is not possible to form test and control groups simultaneously in the state of Florida. This situation dictated that the necessary isolation between the citrus growers comprising the control and test groups would have to arise from either geographic or temporal displacement. Geographic separation was quickly rejected due to problems inherent in comparing the California and Florida citrus industries. Thus it was necessary to establish the control group by time displacement, either by using existing historical cost and loss data as kept by growers, or by control group data collection during the 1976-77 and 1977-78 seasons and test group data collection during the 1978-79 frost seasons. The temporal displacement approach

introduces a number of confounding variables, many of which can be taken into account in the experiment design and conduct and several of which cannot. As will be seen in following pages, frost/freeze variations from season to season are accounted for. Citrus price variations from season to season have also been taken into account. The experiment is designed to measure the economic consequences of improved frost/freeze forecasts. The experiment is not designed to ascertain what has caused the improvement in the accuracy of frost/freeze forecasts be it the satellite data, the forecast models, improved forecaster skill, changes in procedures, etc. To measure these latter effects would require a significantly different approach requiring an analysis of actual and forecast weather events over many frost seasons. It should be noted that the experiment to measure the economic consequences of improved forecasts can proceed independently from an experiment to determine the cause of the improved forecast accuracy. The former is a relatively short duration experiment requiring the involvement of the citrus growers whereas the latter is a relatively long duration experiment which does not require the involvement of the citrus growers.

The use of historical data appeared to be possible but highly risky. Numerous discussions with citrus growers in Florida indicated that there was, in general, a lack of the detailed data which was necessary to establish a statistically significant sample of costs and losses. Furthermore, the risk associated with the historical approach was compounded by the impact of fuel price increases over the past three years. Growers who would have fired all their heaters at 26°F, for example, now only fire the cold spots. Therefore, it was finally decided to establish a control group during the 1976-77 season. The same growers who participated during the 1976-77 season could then continue to participate during the 1977-78 and 1978-79

frost seasons as control or test groups depending upon the availability of the data from the University of Florida forecast model.

The participants in the experiment are indicated in Figure 1.1. The basic timetable of the experiment is as follows. During the 1976-77 frost season, the National Weather Service provided frost and temperature forecasts to the citrus growers in a business-as-usual fashion. During the 1976-77 frost season, a selected set of citrus growers provided data on actual temperatures, decisions made and actions taken. These growers also provided cost and loss related data. The National Weather Service provided data pertaining to temperature forecasts and actual observed temperatures (in the form of thermographs). Because of the delay encountered in bringing the improved forecasting capability on-line, similar data for the control group was also collected during the 1977-78 frost season. These

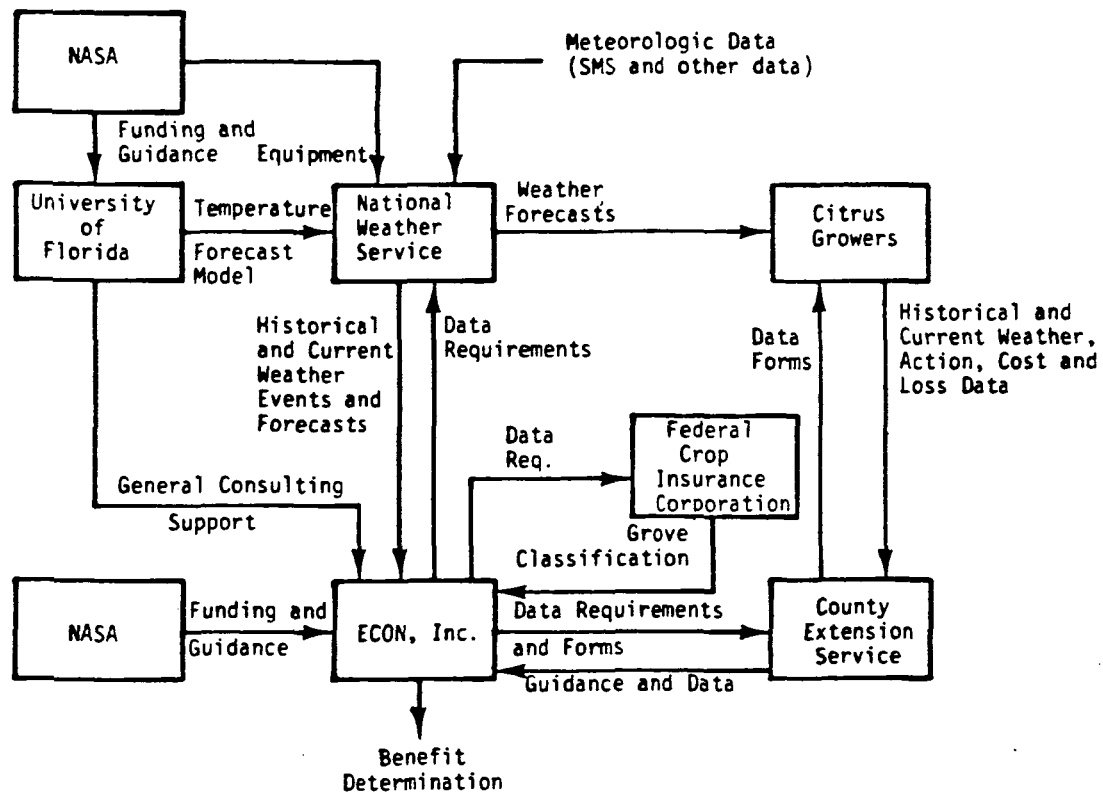


Figure 1.1 Participants in the Florida Economic Experiment

data have been analyzed by ECON and the average cost and loss per event determined for each of the control group frost seasons and the results compared (see Section 5).

Current plans call for repeating the above process during the 1978-79 frost season. The current schedule calls for the SMS/GOES data, together with the University of Florida forecasting models, and improved computer and data display equipment, to be used by the National Weather Service during the 1977-78 frost season.

The data provided by the test group will, as in the case of the control group, yield average cost and loss per event. As described in following pages, both the control and the test group cost and loss per event data can be extrapolated to the annual cost for the Florida citrus industry for an average frost season (see Section 5). The difference between the control group and test group annual costs and losses extrapolated to an average frost season will provide an estimate of the average annual benefits which are a direct result of the improved forecasts. If NWS procedures and basic skill levels remain invariant during the course of the experiment, the forecast improvement may be attributable to the combination of SMS/GOES data and the University of Florida forecasting model. These benefits will include the reduction of citrus grower frost protection costs and the reduction of crop losses that are the result of improved decisions which are due to the improved forecasts. The benefit assessment will not include, because of the limited number of frost seasons and, hence, data samples, those benefits which are the result of better marketing decisions made possible by the improved temperature distribution knowledge provided by the SMS/GOES data.

The task of determining economic benefits for the Florida citrus industry is not as easy as it first appears, due to the following major difficulties:

- Accounting for factors which influence the sample grower's frost protection decisions, although these factors are not related to improved temperature forecasts
- Accounting for differences in cold weather severity between the 1976-77, 1977-78 and 1978-79 frost seasons
- The construction of a representative sample that is not too costly.

These points are discussed in the following paragraphs.

Figure 1.2 illustrates, in a simplified form,^{*} 16 various events that are of concern to the experimenter in terms of actual weather conditions, NWS forecast, grower belief of the NWS forecast and grower actions. The actions which are possible on the part of the citrus grower are classed as protect or no-protect actions. Protective action implies the utilization of heating devices and/or wind machines. No protection implies the lack of utilization of heating devices and/or wind machines. The no-protection events are subdivided so that no-protect situations which arise from either too short notice to take protective action or other constraints (for example, inoperative equipment) are clearly delineated. For each of the events or situations there are costs and losses. The only costs of concern are those associated with frost protection, C_I , and losses which result from inadequate or lack of protection, L_I . N_I represents the number of days out of N that the I -th event has occurred during the frost season. (Sections 5.2 and 5.3 present the details of the citrus grower cost and loss models). For example, consider event $I=13$. This represents the situation where frost which was forecasted actually occurred and the grower believed the forecast and protected his grove; protection costs and losses (possibly zero) were incurred which were dependent upon the severity of the frost. For the case $I=9$, where frost was

*The methodology described herein is, for the sake of clarity, a simplification of that actually employed and is presented to convey only the general concept and content of the experiment. The actual detailed procedures differ only slightly and are described in following sections.

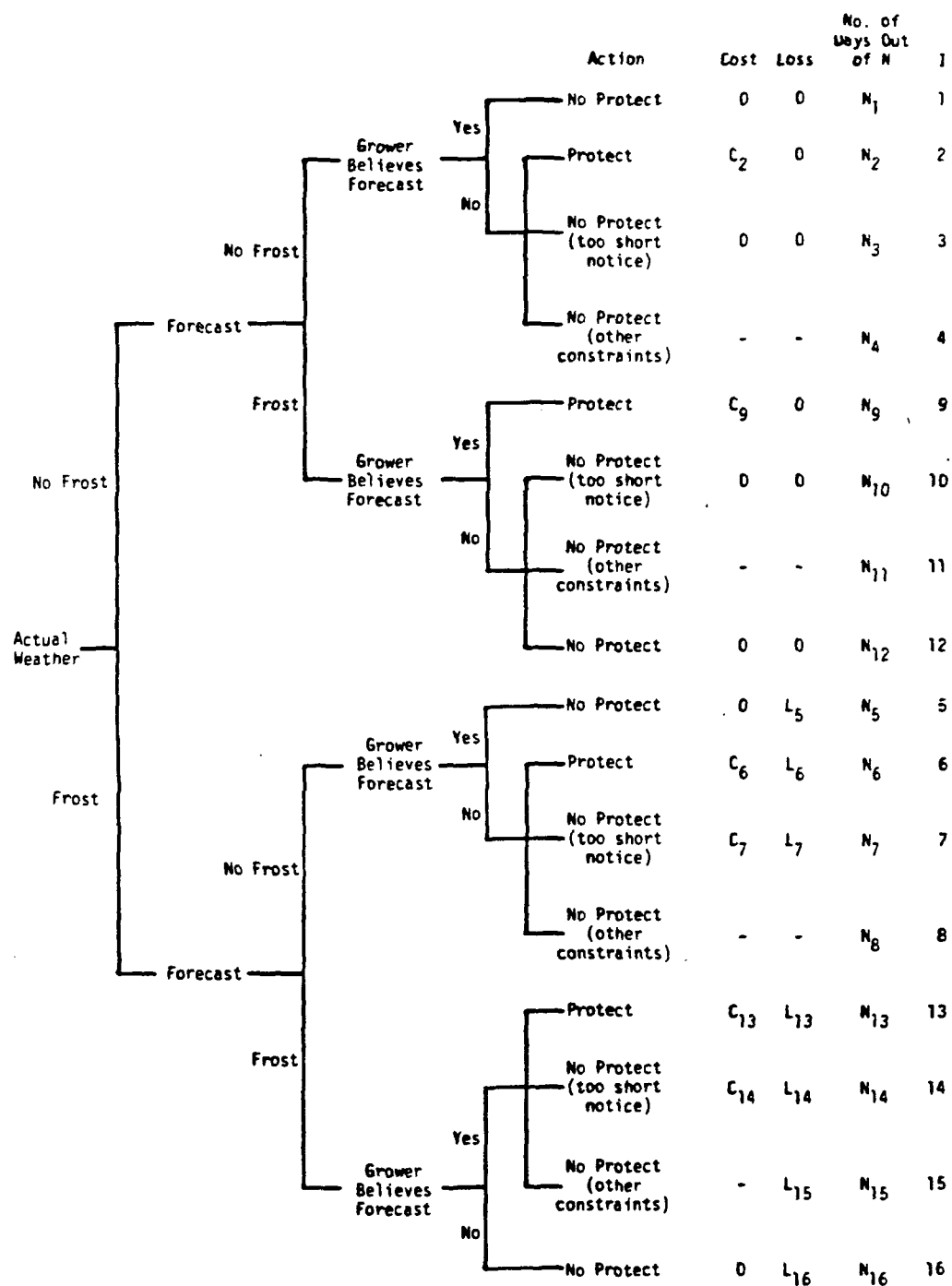


Figure 1.2 Event Descriptions

forecasted but did not occur (i.e., false alarm), and the grower believed the forecast, protective action was taken and protection costs incurred but no crop losses occurred.

Note that all of the C, L and N variables have been subscripted by I, the event as illustrated in Figure 1.2. This has been done for the sake of simplification. In general, a more complex subscripting notation is employed of the form:

I = event type

J = citrus grower type

K = citrus grower identification (i.e., grove designation)

M = frost severity index

D = day.

J is an index which represents citrus grower type where geographic, operating practices and crop differences are taken into account. Thus each participating citrus grower, at the individual grove level, will fall into one of the J types. K is an index which represents the identity of the groves within the J classification. The K-th grove represents the smallest geographic sector for which data are available and/or the largest sector for which constant weather, decision, cost and loss characteristics exist. The sample growers, indicated by the K subscript, may be classified by type and grouped accordingly.

For the purpose of this analysis, it was necessary to develop a reference frame which could be utilized to compare frost protection and loss data obtained for like events within a frost season and during different frost seasons. For this purpose, the M index is employed and corresponds to the relative damage potential of specific ranges of frost intensity and duration (see Section 3.6). The damage potential, considered separately for fruit and trees, is related to degree-hours per day below a baseline temperature (for example, 28°F). The assumed relationship,

as estimated by the University of Florida, is as illustrated in Figure 1.3, where zero implies no damage or loss and ten implies total loss. Appendix A presents a brief discussion of the physics and physiology of frost protection.

Therefore, with the above notation in mind, on any particular day, D , a grower will experience, in general, costs associated with protection, $CST_{I,J,K,M,D}$, and losses, $LOS_{I,J,K,M,D}$, resulting from inadequate or lack of protection when frost occurs. Therefore, the like event costs and losses averaged over a frost season are:

$$EXP_{I,J,K,M} = \frac{1}{N_{I,J,K,M}} \left\{ \sum_{D=1}^{MAXD} CST_{I,J,K,M,D} + \sum_{D=1}^{MAXD} LOS_{I,J,K,M,D} \right\}$$

where $N_{I,J,K,M}$ is the number of days, during the time period consisting of $MAXD$ days, that the event or situation I occurred with "magnitude" characterized by M to the K -th grove of type J . Note that events associated with $I = 4, 8, 11$ and 15 are not to be considered in the cost and loss computations. The reason for this is that these events are the result of constraints upon the grower choices of action which have little or nothing to do with the weather forecasts, actual weather and grower believability of the forecasts.

As mentioned previously, the M subscript is a measure of the severity of the frost and is related to the degree-hours of frost. The severity of the frost (in terms of the degree-hour measure) cannot normally be measured in the grove which has undergone protective action since the protective action, as is its purpose, perturbs the temperature that would have occurred if protective action had not been taken. Therefore, it is necessary to obtain temperature profile measurements on control thermometers of the NWS or other nearby locations where temperatures are not perturbed by the protective actions of growers and, thence, to relate these temperature profiles to those which would have occurred in

Temp. [°F]	Degree Hours At A Given Temperature											
	1	2	3	4	5	6	7	8	9	10	11	12
28	0/0	0/0	0/0	0/0	0.5/0	0.75/0	1/0	1.25/0	1.5/0	1.75/0	2/0	2/0
27	0/0	1/0	2/0	2/0	3/0	4/0	4.25/0	4.5/0	4.75/0	5/0	5/0	5/0
26	0/0	1/0	2/0	3/0	4/0	4.3/0	4.6/0	5/0	5/0	5/0	5/0	5.5/0
25	1/0	2/0	3/0	4/0	4.5/0	5/0	5.2/0	5.4/0	5.5/0	5.7/0	5.85/0	6/0
24	1.5/0	2.4/1	4/1	4/1	4.5/1	5/1	5.3/1	5.7/1	6/2	6.5/2	7/2	8/2
23	2/1	2.7/1	4/1	4.1/1.2	5/1.5	6/1.75	7/2	7.5/2.2	8/2.4	9/2.6	10/2.8	10/3
22	2.5/1.3	3/1.6	4/1.8	5.5/1.9	7/2	8/2.3	10/2.6	10/2.9	10/3.2	10/3.5	10/3.8	10/4
21	3/2	3.5/2	5/2	6.5/2	8/3	10/3	10/3	10/3	10/3.5	10/4	10/4.5	10/5
20	4/2.5	5/2.75	6/3	8/3.3	10/3.6	10/4	10/4.3	10/4.6	10/5	10/5.6	10/6.3	10/7
19	4.5/3	6/4	7.5/5	9/5.5	10/6	10/6.3	10/6.6	10/7	10/7.5	10/8	10/9	10/10
18	5/4	7/5	9/6.5	10/8	10/9	10/10	10/10	10/10	10/10	10/10	10/10	10/10

Figure 1.3 Preliminary Severity Measure of Frost/Freeze as Estimated by Dr. Gerber and Dr. Bartholic, University of Florida (Note: Upper numbers refer to fruit and lower numbers refer to trees)

the grove if protective action were not taken. It is this latter temperature which is utilized (together with duration) as a measure of grove frost severity. Estimates were obtained of the relationship between specific control thermometers and the groves in the experiment. Adjustments were made as necessary when data was obtained from grower control thermometers. Figure 1.4 illustrates a typical thermograph and the adjustment procedure used for establishing frost severity. (See Section 3.6 for the details of the severity index computation.)

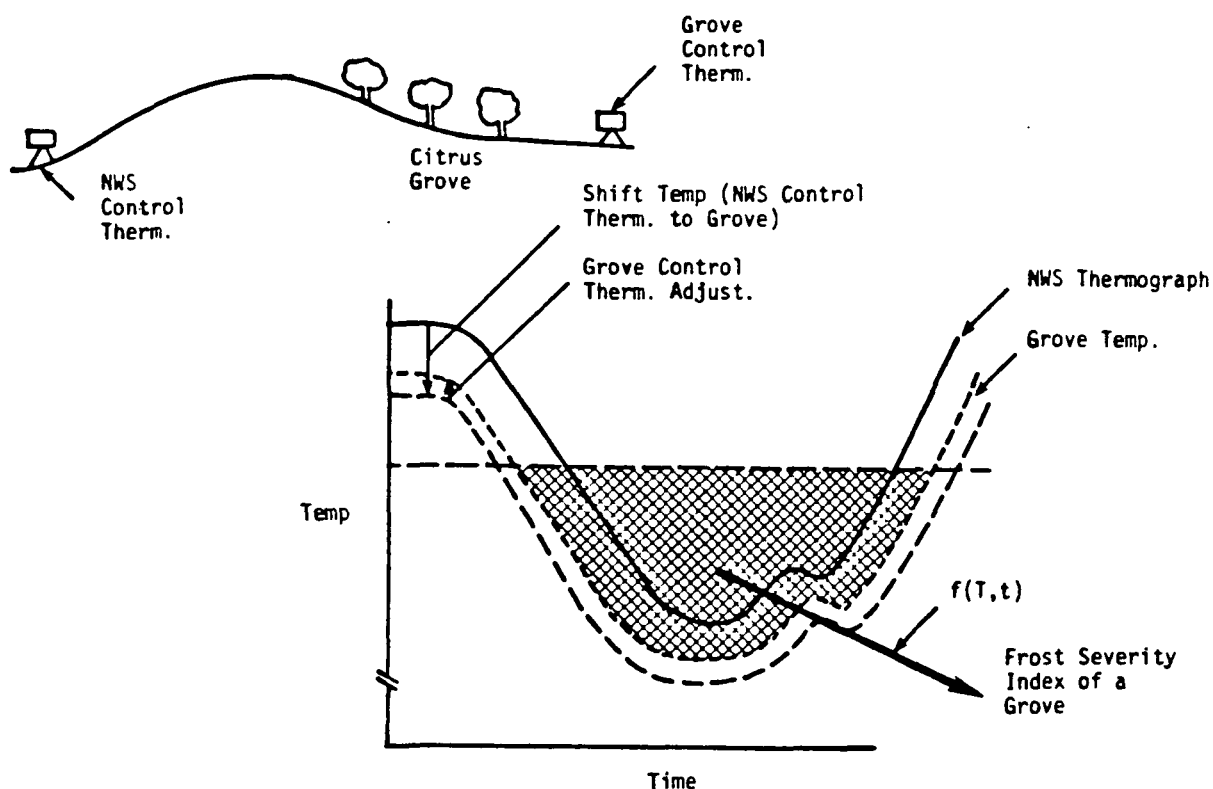


Figure 1.4 Frost Severity Determination

Thus each night of freezing temperatures is characterized by a frost severity index which summarizes its potential impact upon fruit and trees. This characterization is accomplished for each grove along with protection costs and fruit and tree losses. A regression analysis is thence performed (for each fruit type and county) which relates costs and losses to severity of freeze (see Section 5). A hypothetical relationship between severity of freeze and economic costs (protection cost and fruit and tree losses) is illustrated in Figure 1.5. Two curves are shown: without SMS/GOES and with SMS/GOES. The former implies the forecasting capability prior to the use of SMS/GOES control group data using conventional forecasting data in combination with the University of Florida forecasting models (i.e., the control group) and the latter implies the forecast

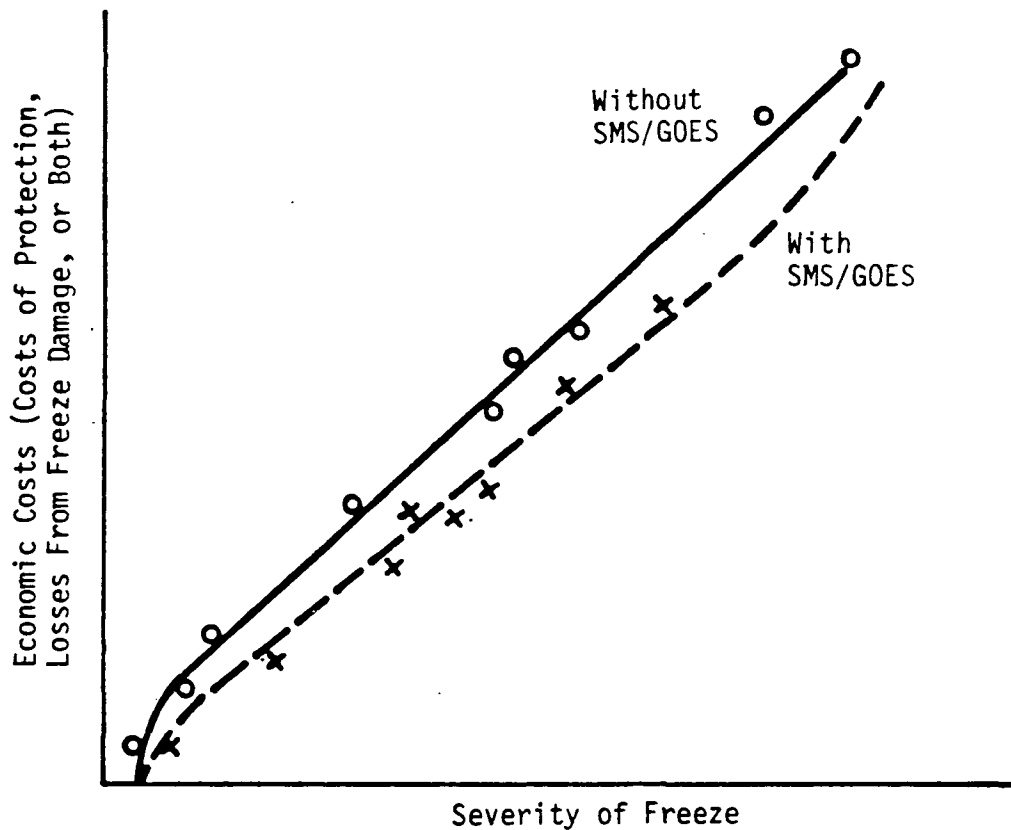


Figure 1.5 Hypothetical Relationship Between Weather Events and Economic Effects With and Without SMS Data

capability which results from the use of the SMS/GOES data and the University of Florida temperature forecasting models (i.e., the test group).

In order to establish a measure of the economic benefits which may result from the improved forecasts that are expected to result from the use of the SMS/GOES data and the University of Florida temperature forecasting models, it is necessary to compare the economic costs of the control and test groups as they would have occurred for the same frost season. It should be remembered that the control group data was collected during the 1976-77 and 1977-78 frost seasons and test group data will be collected during the 1978-79 frost season. It should also be

noted that none of these frost seasons may be normal or "typical." To ensure that a fair comparison is made of the control and test group results, 30 years of control thermometer temperature data (temperature as a function of time) was obtained from the National Weather Service. This allows 30 frost seasons to be characterized in terms of the severity of freeze index and normal or average frost seasons to be characterized in terms of the number of frost days of different severity levels. This characterization is accomplished at the individual grove level.

Thus the average annual benefits, $\bar{B}$, can be obtained as

$$\bar{B} = \sum_{M,G} N_{M,G} * [EC_{M,G} - EC'_{M,G}]$$

where $N_{M,G}$ is the number of days of severity M at grove G and EC and EC' represent the economic costs of the control and test group groves, respectively.

To summarize briefly, the economic benefits of improved temperature forecasting capability will be obtained as the result of establishing the relationship between costs and losses and freeze severity and other explanatory variables and thence specifying a normal or average frost season in terms of the number of days of different levels of freeze severity. Data have been collected during the 1976-77 and 1977-78 frost seasons which permits the establishment of the cost/loss/freeze severity relationship for the control group. Data will be collected during the 1978-79 frost season to establish the cost/loss/freeze severity relationship for the test group. Data have been obtained from the NWS and a normal or average frost season has been characterized in terms of the number of days of different levels of frost severity. Upon completion of test group data collection, the economic benefits of improved temperature forecasting will be obtained.

The overall experiment has been described. The establishment of costs and losses per event is now discussed. Cost and loss per event are obtained from the manipulation of data provided by the citrus growers for each of the groves contained within the experiment sample (see Section 5). Grove data is provided primarily on three separate forms: Grove Background Report, Nightly Frost/Freeze Protection Activity Report and Damage Report. The Grove Background Report was filled out prior to the start of the 1976-77 frost season and updated for each of the following seasons. It provides the following information for each grove: identification and location; citrus variety and rootstock; grove age and percentage resets; grove area, terrain, soil type and influence of large bodies of water; FCIC classification; availability of control thermometer data; month of harvest; average yield for each of the past three seasons; estimate of yield for current season; original intent to produce for fresh or processed market and reasons for choice; wind machines and/or heaters (type, number, type of fuel, average fuel consumption rate).

The Nightly Frost/Freeze Protection Activity Report, filled out only if a fruit frost bulletin by the NWS predicted the lowest temperature to be 28°F or less for the zone within which the grove is located or frost/freezing protection was undertaken (regardless of predicted temperatures) and costs were incurred, provides the following information for each grove: grove identification; date of frost occurrence and/or cost incurrence; specific NWS forecast which influenced action; level of confidence in NWS forecast; labor costs associated with frost/freezing protective action; number and type of wind machines used and time turned on and off; number and type of heaters used and time fired and extinguished; total mileage (trucks and autos) incurred during frost/freezing protective action; minimum temperature recorded on grove control thermometer; observation of damage to

fruit and/or freeze not previously reported; if no protective action was taken, reasons why.

For the 1976-77 frost season, the Damage Report was filled out only when damage was observed to fruit and/or trees. It provided the following information: grove identification and date; the date of frost/freezing which caused damage; type of damage (fruit and/or tree); manner of marketing fruit before and after damage (fresh or processed); estimated yield prior to and after damage; if there was tree damage, an estimate of the number of years to recover to full production. Because of problems of estimating which freeze caused the damage, the damage reporting was modified for the 1977-78 frost season. Damage Reports are now provided at the end of the frost season for each grove that experienced fruit and/or tree damage.

The data obtained from these forms, plus pricing data (fuel, fresh fruit and processed fruit), provides the basis for the establishment of cost and loss per event (see Section 3.4). The cost per event consists of three components, namely, (1) labor costs, (2) fuel costs and (3) automobile and truck mileage cost. The loss per event consists of fruit loss and tree loss. The fruit loss is associated with yield in complex ways. The grower who intended to market fresh fruit may, after suffering damage, simply market fruit for processing, at little loss in total yield but with appreciable loss in dollar value. The grower loss per event takes into account both price changes and yield changes.

Economic gains or losses to the grower are dependent upon what has happened in the industry as a whole. Estimates of the change in expected industry production have been obtained from the Florida Crop and Livestock Reporting Service. From these figures, together with price information and price elasticity, estimates of total industry loss of fresh and processed fruit are derivable and can

thence be prorated to individual groves based upon reported yield reductions and market. Tree damage losses are established as the present value of the production losses in future years due to a particular frost event. This utilizes the grower's estimate of the level of tree damage and the number of years before full recovery. In order to translate reduced production estimates into economic losses it is also necessary to forecast average on-tree prices for several years into the future.

Table 1.2 presents an estimate of the grower survey population in terms of the number of growers, total acreage (Lake, Orange and Polk counties) and number of groves. Estimates are also presented for the number of growers who have protected groves, the number of groves which are protected and the protected acreage. Table 1.2 also indicates the number of growers who are participating in the experiment, the number of groves and their total acreage. During the first

Table 1.2 Estimate of Grower Survey Population and Actual Control Group Size			
	Total Acreage	Growers	Groves
Total*	326,000	7,200	8,000 - 9,000
Frost Protected*	51,000	230	1,200 - 1,300
Frost Protected & Control Group Participants 1976-77	8,616	52	245
Frost Protected & Control Group Participants 1977-78	7,137	39	199
* Lake, Orange and Polk Counties.			

year of the experiment this represented approximately a 20 percent sample based upon number of protected groves and a 17 percent sample based upon protected acreage. These percentages have been reduced, as expected, with time. An effort will be made to increase the sample size during the 1978-79 data collection period. The geographic distribution of the experiment sample population is illustrated in Figure 1.6.

The selection of the sample groves was based upon many factors. The more important factors considered were cooperation of growers and grove managers, geographic location, fruit type and frost protection measures. The County Extension Agents served as the interface with the growers, explaining the data collection forms and collecting and reviewing the grower data.

Typical control group results are summarized in Figures 1.7 through 1.13. Figures 1.7 and 1.8 illustrate the average or mean severity (in terms of the previously described severity of frost index) of frost by date for the 1976-77 and 1977-78 frost seasons, respectively. For the first season, two columns are shown for each day; the column on the left indicates the mean severity when considering only those groves for which freezing temperatures (i.e., below 28°F) were experienced, whereas the column on the right indicates the mean severity when considering all groves in the data base. The difference in the height of these columns is a measure of the lack of uniformity of the frost. Since the 1977-78 season was uniformly mild, Figure 1.7 shows only the mean severity for those groves experiencing freezing temperatures on each night.

Figures 1.9 and 1.10 illustrate the percent of sample groves undertaking protective action on each cold night and Figures 1.11 and 1.12 indicate the average per acre cost of protection on each cold night for groves that experienced protection costs. Figure 1.11 also shows the average per acre cost of protection

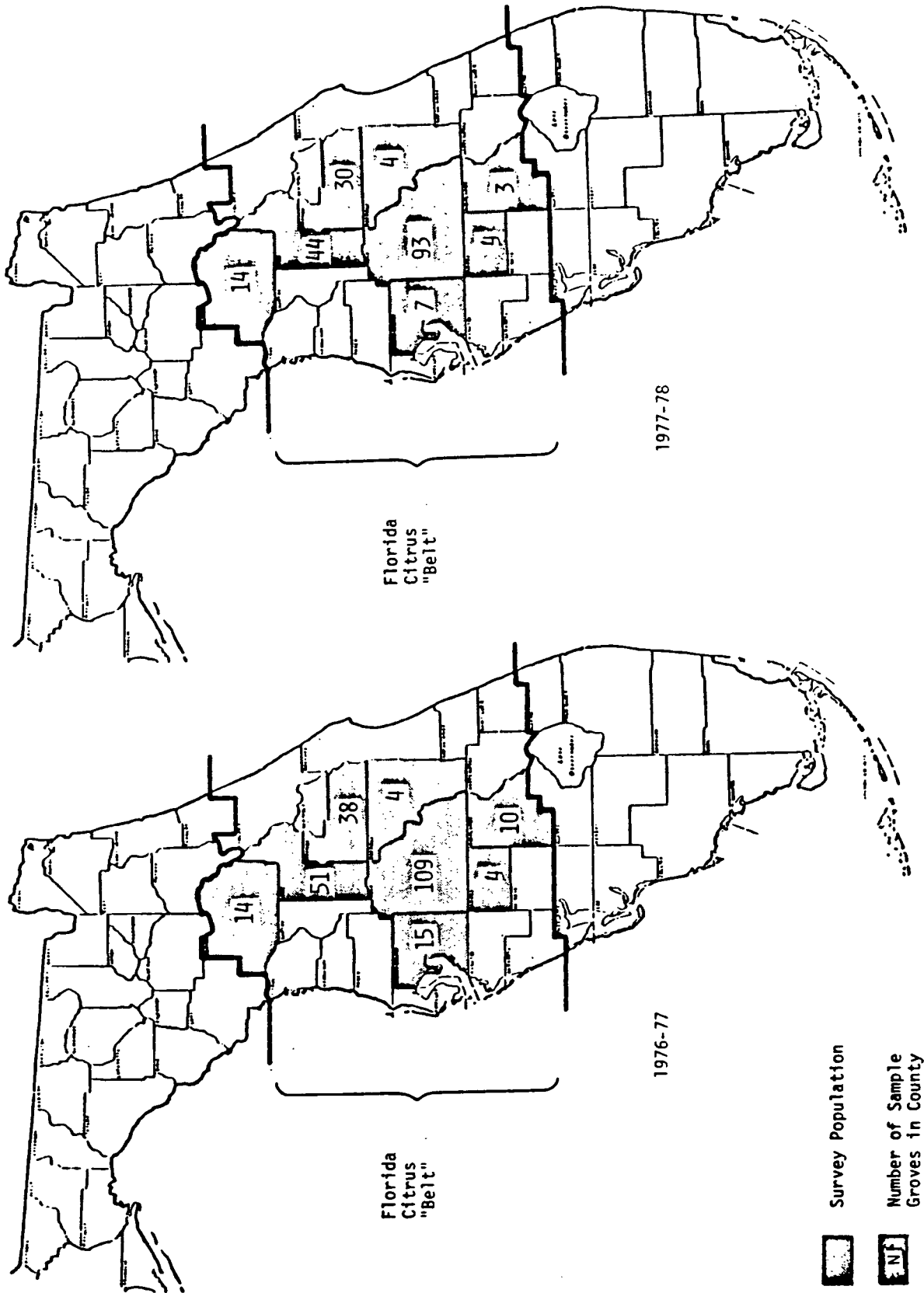


Figure 1.6 Sample Grove Distribution

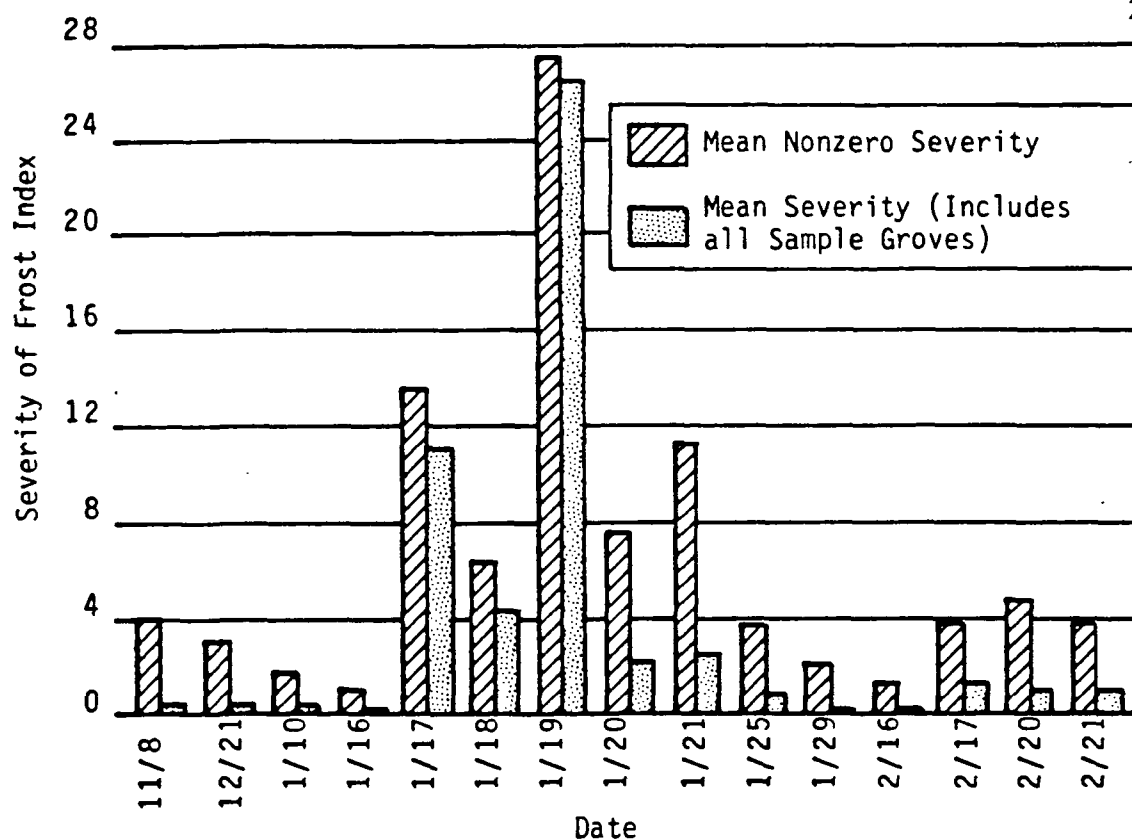


Figure 1.7 Mean Severity of Frost by Date, 1976-77 Frost Season

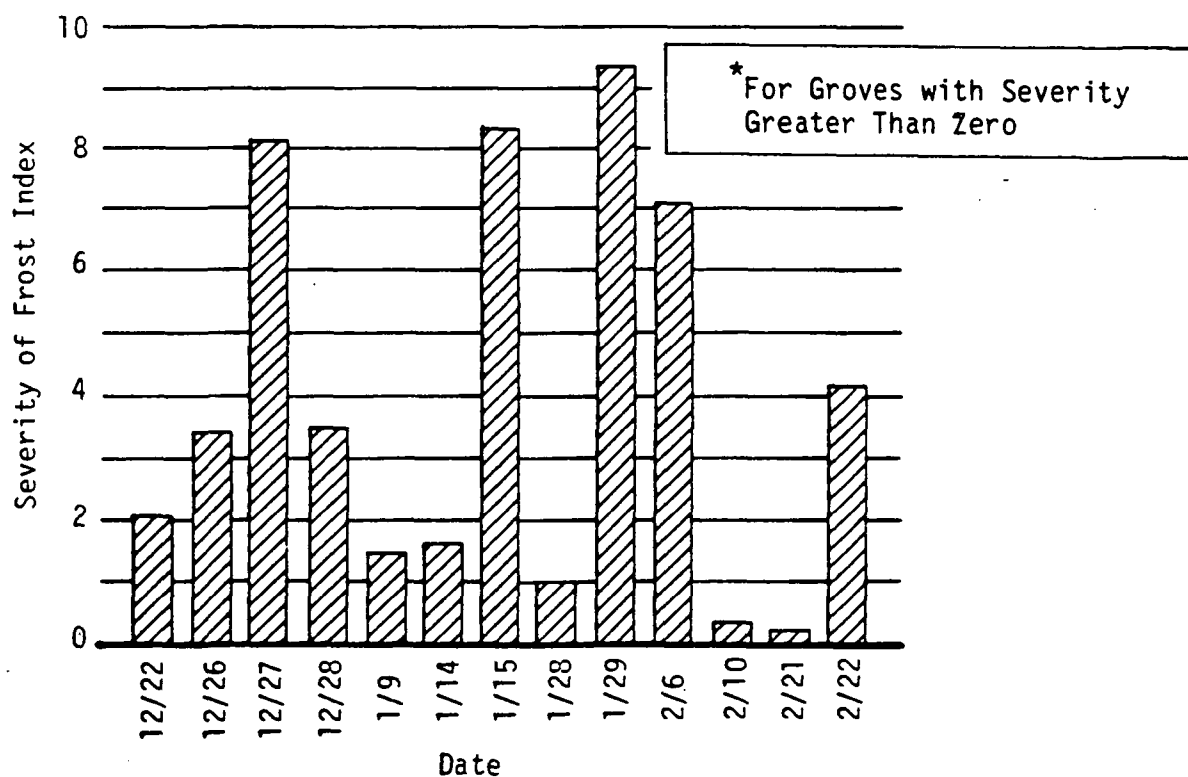


Figure 1.8 Mean Severity of Frost* by Date, 1977-78 Frost Season

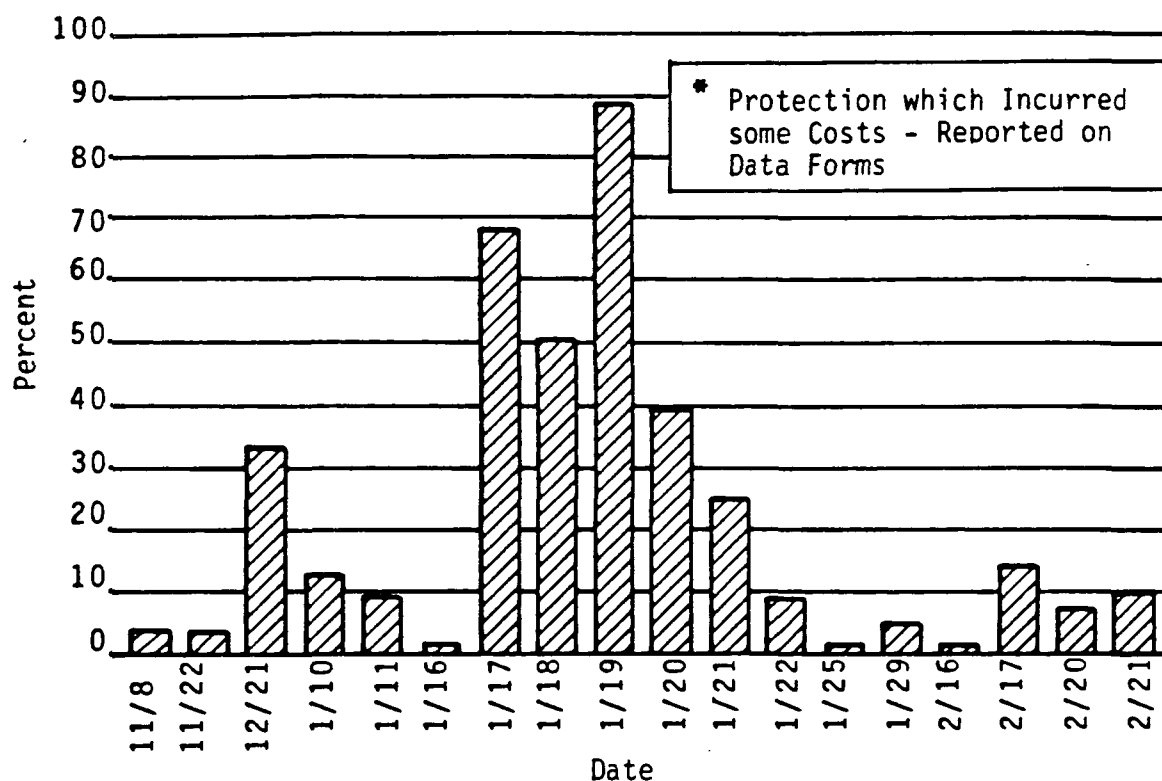


Figure 1.9 Percent of Sample Groves Undertaking Protection*
On Each Cold Night, 1976-77 Frost Season

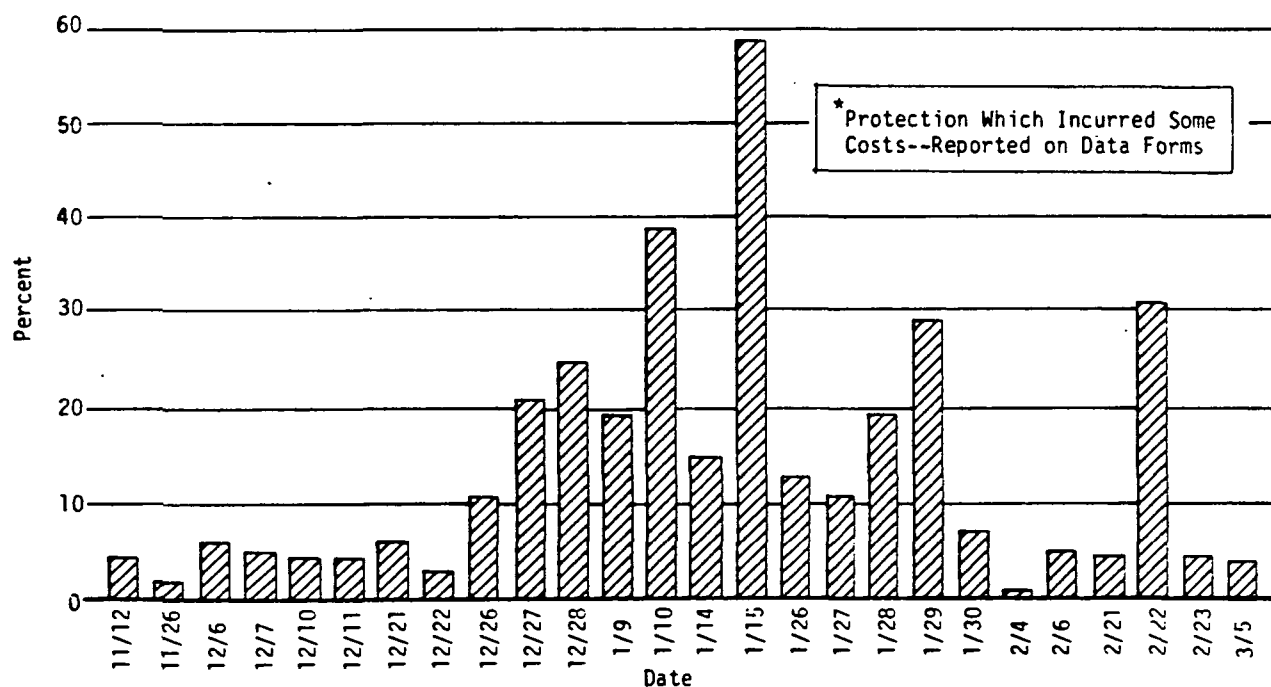


Figure 1.10 Percent of Sample Groves Undertaking Protection*
On Each Cold Night, 1977-78 Frost Season

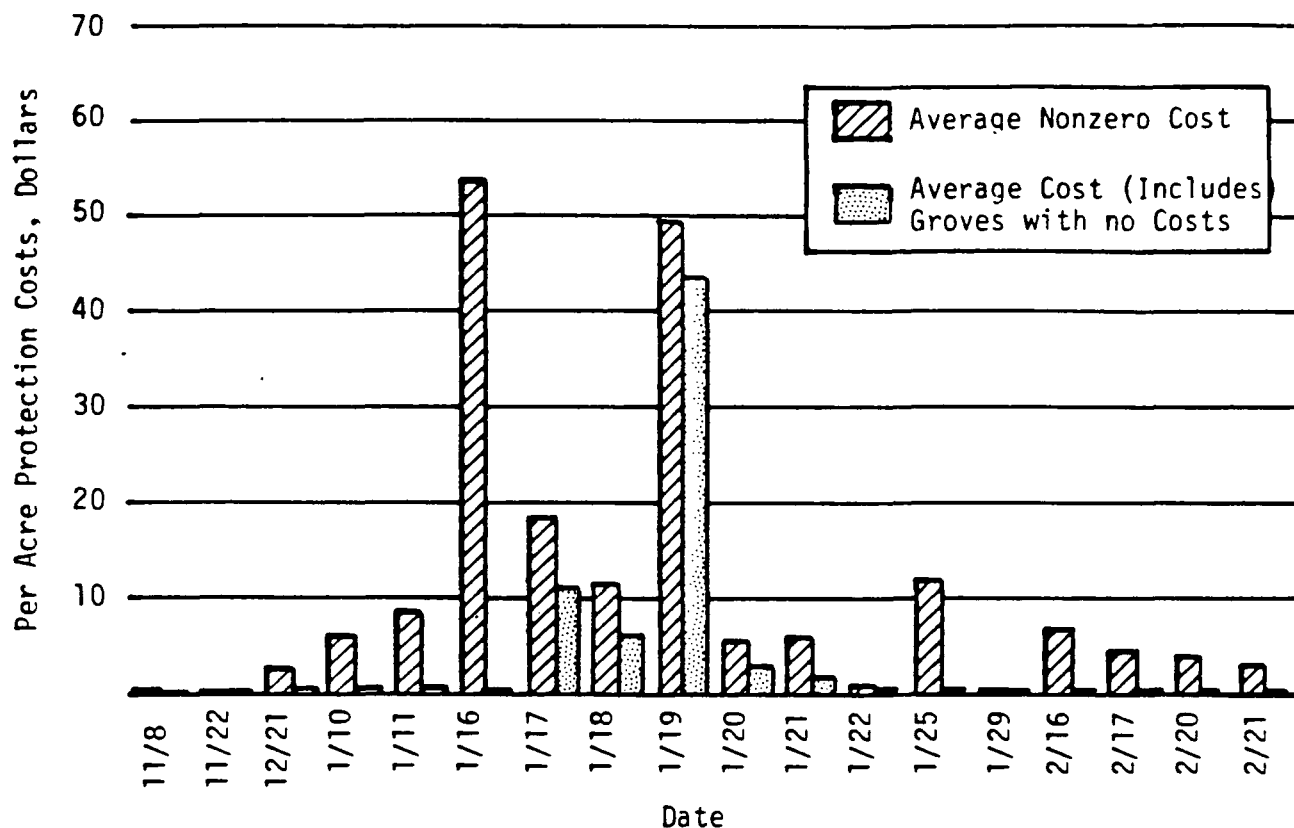


Figure 1.11 Average Per Acre Cost of Protection for Each Cold Night, 1976-77 Frost Season

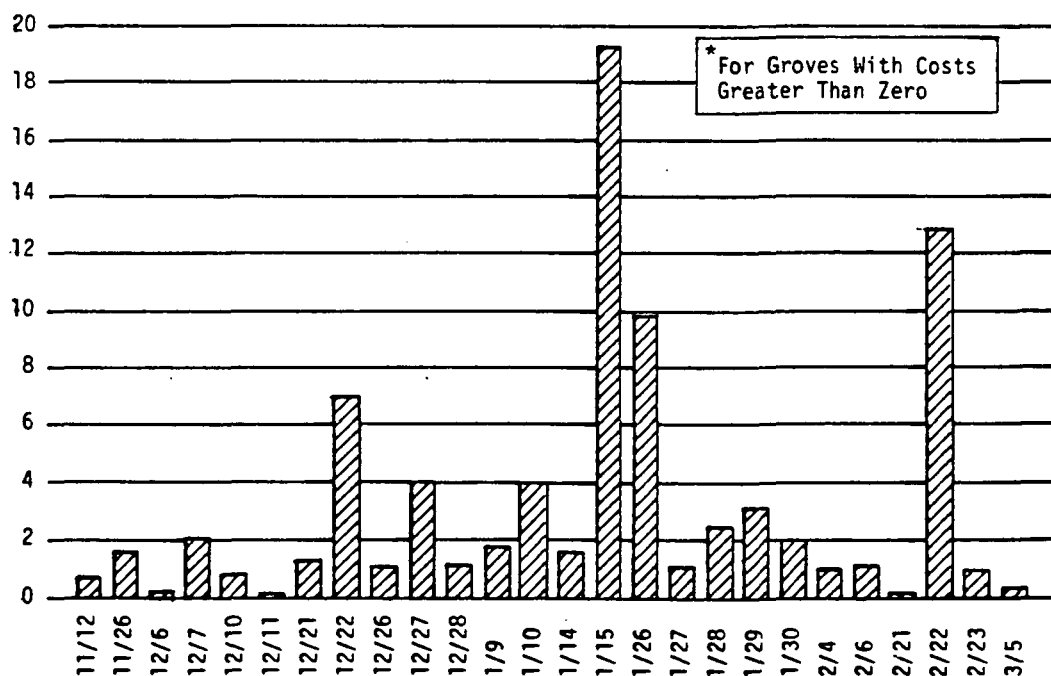


Figure 1.12 Average Per Acre Cost of Protection* for Each Cold Night, 1977-78 Frost Season

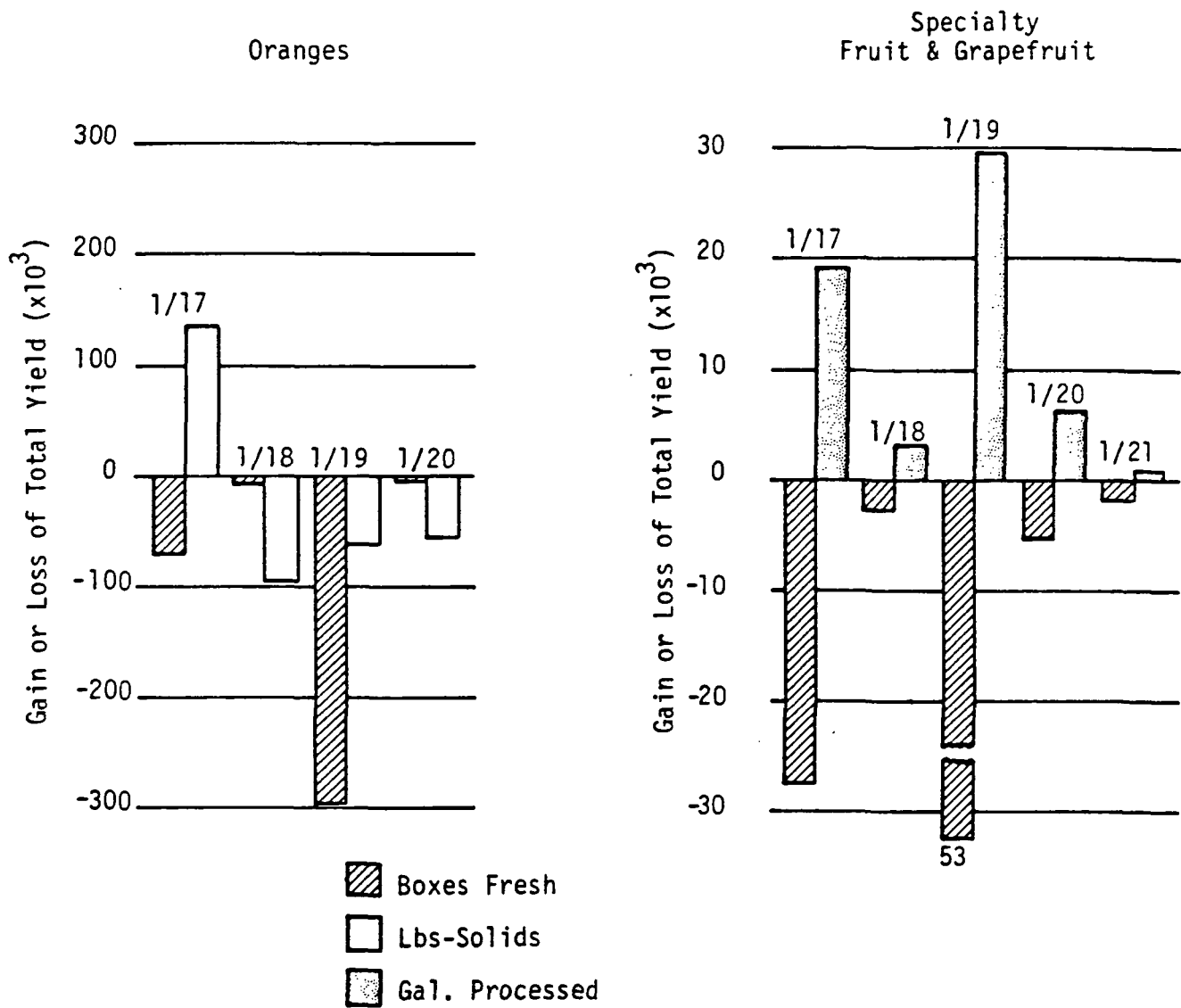


Figure 1.13 Gain or Loss by Night for Groves in Control Group
 Sample Which Suffered Crop Damage During 1976-77
 Frost Season

for all groves in the data base on each cold night. The average cost of protection for the 1976-77 crop year varies considerably by county, ranging from a high of \$109/acre in Hillsborough to a low of \$32/acre in Marion County (see Table 5.5). Because of these large variations, all analyses and extrapolations must be done by citrus variety and county. In both seasons, there were several cold nights on which some growers initiated protective action but for which the frost severity index was zero. In general, it is expected that the number of nights on which at least one grower took action will exceed the number of nights with positive frost severity, due to uncertainties caused by imperfect information.

Figure 1.13 indicates the physical losses for all groves in the 1976-77 control group sample, by frost date. Because of the lack of severe freezes during the 1977-78 frost season there is no meaningful comparable data for that season. There are two types of losses that can occur due to a freeze. One is a loss of quantity, when fruit is so badly damaged that it drops to the ground or is not worth picking. The second is a loss of quality, when fruit which was originally intended for the fresh market is no longer suitable for fresh sale and must be processed, or when fruit intended for processing loses some of its sugar and juice content so that its yield in pounds-solids declines.

During the 1976-77 frost season, some growers in the sample experienced total losses of all or part of their fresh or processed fruit. Most were able to save their fruit by diligent protection, but in many cases the damage caused a shift of marketing plans from the fresh sector to the processed one, or a loss in pounds-solids. On the average, during the 1976-77 frost season, a large amount of fresh fruit was lost as a result of each of the frost/freeze nights, but due to the shift from fresh to processed, there was a samplewide gain in pounds-solids. Because of

some absolute losses, and because of the overall decline in the juice and sugar content in the total crop, these gains do not totally offset the fresh fruit losses.

Figure 1.13 indicates, for 1976-77, the loss of fruit intended for the fresh fruit market and the gain in fruit for the processed market--the gain is the net of fruit intended for fresh but marketed as processed and the yield reduction of that fruit originally intended as processed.

Regression analyses have been performed on the control group data (see Section 5) and indicate that the best predictors of labor cost are minimum temperature forecast and duration of temperatures below 28°F. The best predictors of nonlabor cost include these two weather-related variables and labor cost. The regression analyses also indicate that frost severity and nonlabor cost are good predictors of losses. The developed regression equations for the control group are of the form indicated below.

$$\begin{aligned} \text{Costs:} \quad \ln^*(\text{LABOR} + 1) &= \beta_0 + \beta_1 (\ln(\text{DUR28} + 1)) + \beta_2 \text{MINFOR} \\ \ln(\text{NONLAB} + 1) &= \beta_0 + \beta_1 (\ln(\text{LABOR} + 1)) + \beta_2 (\ln(\text{DUR28} + 1)) \\ &\quad + \beta_3 \text{MINFOR} \end{aligned}$$

$$\text{Losses:} \quad \text{LOSSPA} = \beta_0 + \beta_1 \text{NONLAB} + \beta_2 \text{FSEV}$$

where $\beta_0, \beta_1, \dots, \beta_n$ = estimated regression coefficients

LABOR = per acre labor costs

NONLAB = per acre nonlabor costs

DUR28 = duration of temperature below 28°F

MINFOR = minimum of temperature forecast range

LOSSPA = per acre dollar loss

FSEV = frost severity index.

* Natural logarithm.

The regression coefficients are estimated separately for each type of fruit, location (northern or southern citrus producing counties) and frost season.

It should be noted that cost cannot be adequately predicted by frost severity alone. The use of minimum temperature forecast as one of the predictors of cost adds a complication to the comparison of costs and losses of the control and test groups during an "average" frost season. The 30-year NWS temperature tape provides the necessary statistics for actual temperatures and their durations. It is necessary to determine the probability distribution of forecast error for cold nights for the control and test groups. The actual comparison of the control and test group results will then consist of a Monte Carlo simulation using the established regression equations (for the control and test groups) and the 30-year temperature data and sampling the forecast error distributions. The sampling of the forecast error distribution together with the actual minimum temperature will yield the temperature forecast which is required by the cost regression equation.

The data presented in the previous tables and figures are based upon information provided by the Florida citrus growers. The basic data for the 1976-77 frost season were provided by 52 growers covering 245 groves; 2150 Nightly Frost/Freeze Protection Reports were provided by the growers. These reports were filed whenever a frost was forecast (i.e., less than 28°F) and/or costs or losses were incurred. Approximately 86 percent of the reports, as per the filing criteria, were submitted by the growers. Two hundred eighty-seven Damage Reports were also filed by the growers. These reports were required whenever damage was observed. Approximately 90 percent of the anticipated damage reports were submitted by the growers.

The data for the 1977-78 frost season were provided by 39 growers covering 199 groves; 2884 Nightly Frost/Freeze Protection Reports were provided by the growers. These reports, as during the previous frost season, were filed whenever

a frost was forecast and/or cost or losses were incurred. Approximately 92 percent of the reports, as per the filing criteria, were submitted by the growers. Damage Reports were also filed by the growers. These reports were filed at the end of the frost season for each grove that had observed damage. Approximately 98 percent of the anticipated damage reports were submitted by the growers.

The economic experiment has been summarized in the previous pages and is discussed in detail in the following pages. Results of the control group data collection and analyses have been summarized in terms of control group costs and losses. At this point in time it is not possible to establish the benefits of improved temperature forecasting to the Florida citrus growers since this must await test group data collection and analysis and the comparison of the control and test group results. Thus, future efforts will be devoted to a repeat of the previously described data collection and analysis but with the improved temperature forecasting capability being available. A comparison of the test group results with the control group results will then be accomplished.

2. FROST/FREEZE FORECASTS AND THE FLORIDA CITRUS INDUSTRY

Frost/freezing forecasts play an important role in the decision process of growers concerned with the protection of their citrus groves from the damaging effects of low temperatures. In order to assess the value of frost forecasts to the Florida citrus industry it is necessary to understand the industry's production values, the relation of citrus producing regions' climate and their geographical distribution, the weather sensitivity of citrus, as well as the role of the National Weather Service in the frost forecasts, and the frost protection methods and decision processes.

This section provides an overview of the Florida citrus industry so that the economic portion of the Florida temperature forecasting experiment can be viewed in the proper perspective.

2.1 Geographical Distribution and Production Value of Citrus Producing Regions

The areas in the United States which are most suitable for citrus production are located predominantly in the subtropical regions of the southeast and southwest (Figure 2.1). These regions have climates which are relatively free from freezing temperature and wind hazards. Florida is the major producing region with almost 75 percent of the total U.S. production. The second largest citrus growing region is southern California. Additional areas having important citrus crop production are located in Texas and Arizona.

The general term "citrus" includes early, midseason and late (valencia) oranges, grapefruits, tangerines, tangelos, temples, lemons and limes. The major citrus products are oranges and grapefruits with the remainder normally referred



Figure 2.1 Citrus Producing Regions in the U.S.

to as "specialty fruit." Lemons and limes are grown in the most southern part of Florida where low temperatures rarely occur.

The total U.S. citrus-producing acreage and production is listed by state, for the 1956-77 time period, in Table 2.1. There was a total of 1,184,700 citrus-producing acres in 1977 (excluding honey tangerines, limes and lemons) of which 794,900 acres (67.1 percent) are in Florida. The detailed geographical distribution of the two main citrus products, oranges and grapefruits, throughout Florida is shown in Figures 2.2 and 2.3, respectively.

The United States is the leading producer of citrus in the world. The total world production of oranges in the year 1976 season was 748.0 million boxes, of which 252.5 million (33.8 percent) were produced in the United States. As far as the grapefruit production is concerned, the United States share is even larger. From the total worldwide crop of 92.5 million boxes, over 76 percent (70.6 million boxes) were grown in the United States according to the Foreign Agricultural Service of USDA.

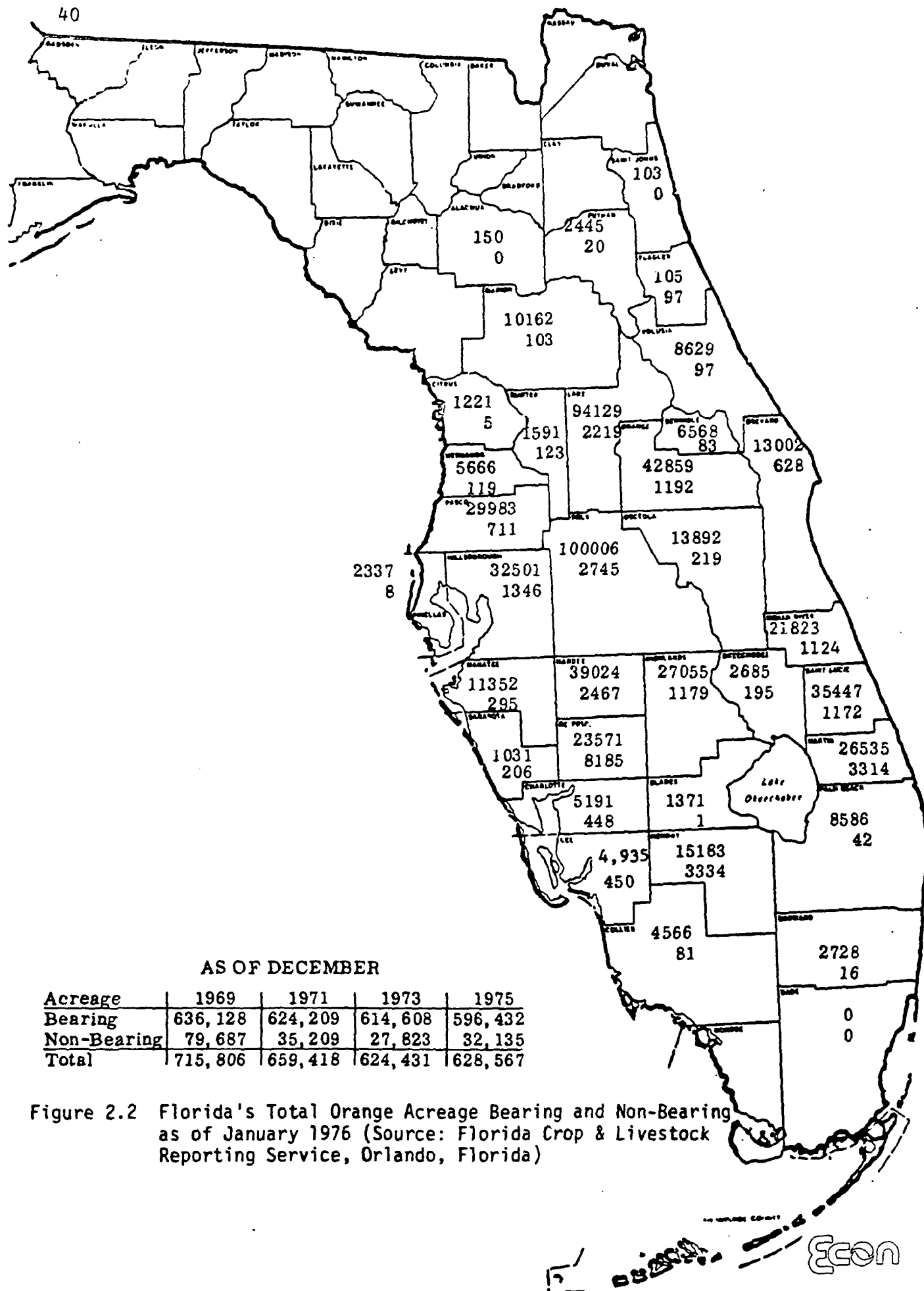
Table 2.1 Principal Citrus Fruits: Bearing Acreage and Production,
by States, Crop Years 1956-57 Through 1976-77

Crop Year	Florida		California		Texas		Arizona		United States ²	
	Bearing Acreage 1,000 Acres	Production ¹ 1,000 Tons	Bearing Acreage 1,000 Acres	Production 1,000 Tons	Bearing Acreage 1,000 Acres	Production 1,000 Tons	Bearing Acreage 1,000 Acres	Production 1,000 Tons	Bearing Acreage 1,000 Acres	Production 1,000 Tons
1956-57	536.2	6,025	210.1	2,025	56.7	184	13.6	118	821.1	8,357
1957-58	493.6	5,164	207.2	1,581	59.1	230	13.8	136	777.2	7,120
1958-59	490.6	5,591	202.4	2,219	65.1	271	14.9	96	776.9	8,187
1959-60	508.2	5,581	197.9	1,879	71.1	329	17.3	202	798.0	8,003
1960-61	513.4	5,512	195.3	1,537	76.1	429	18.4	139	806.6	7,629
1961-62	548.1	6,830	190.8	1,438	78.8	211	20.3	182	838.4 ¹	8,673
1962-63	497.0	4,773	185.1	1,625	71.0	5	22.3	147	775.4	6,550
1963-64	507.3	3,969	186.5	1,974	62.9	31	24.4	252	781.4	6,226
1964-65	557.1	5,480	181.3	1,802	62.8	120	26.7	231	830.3	7,633
1965-66	598.7	6,242	187.3	2,044	64.8	211	30.3	271	881.1	8,768
1966-67	653.0	8,643	192.8	2,139	68.6	338	37.3	316	951.7	11,436
1967-68	692.4	6,364	201.9	1,406	72.6	193	34.6	367	1,001.5	8,330
1968-69	746.1	8,008	213.5	2,316	80.8	471	34.2	421	1,074.6	11,216
1969-70	817.1	8,308	197.2	2,130	75.9	395	32.2	513	1,122.4	11,346
1970-71	866.7	8,785	203.0	2,118	79.0	683	37.0	349	1,185.7	11,935
1971-72	824.2	8,760	213.1	2,368	80.1	629	40.4	403	1,157.8	12,160
1972-73	820.2	10,124	221.9	2,497	70.0	804	50.8	469	1,162.9	13,894
1973-74	817.3	10,088	269.1	2,285	67.5	709	52.7	330	1,206.6	13,412
1974-75	812.7	10,337	272.7	3,197	64.1	485	55.6	573	1,205.1	14,592
1975-76	796.2	10,943	272.1	2,832	64.1	692	61.2	316	1,193.6	14,783
1976-77	794.9	11,179	267.4	2,847	63.9	789	58.5	458	1,184.7	15,273

¹Does not include lemons, honey tangerines or k-early citrus fruit.

²Years before 1965-66 include some data for other states.

Source: Florida Crop & Livestock Reporting Service, Orlando, Florida.



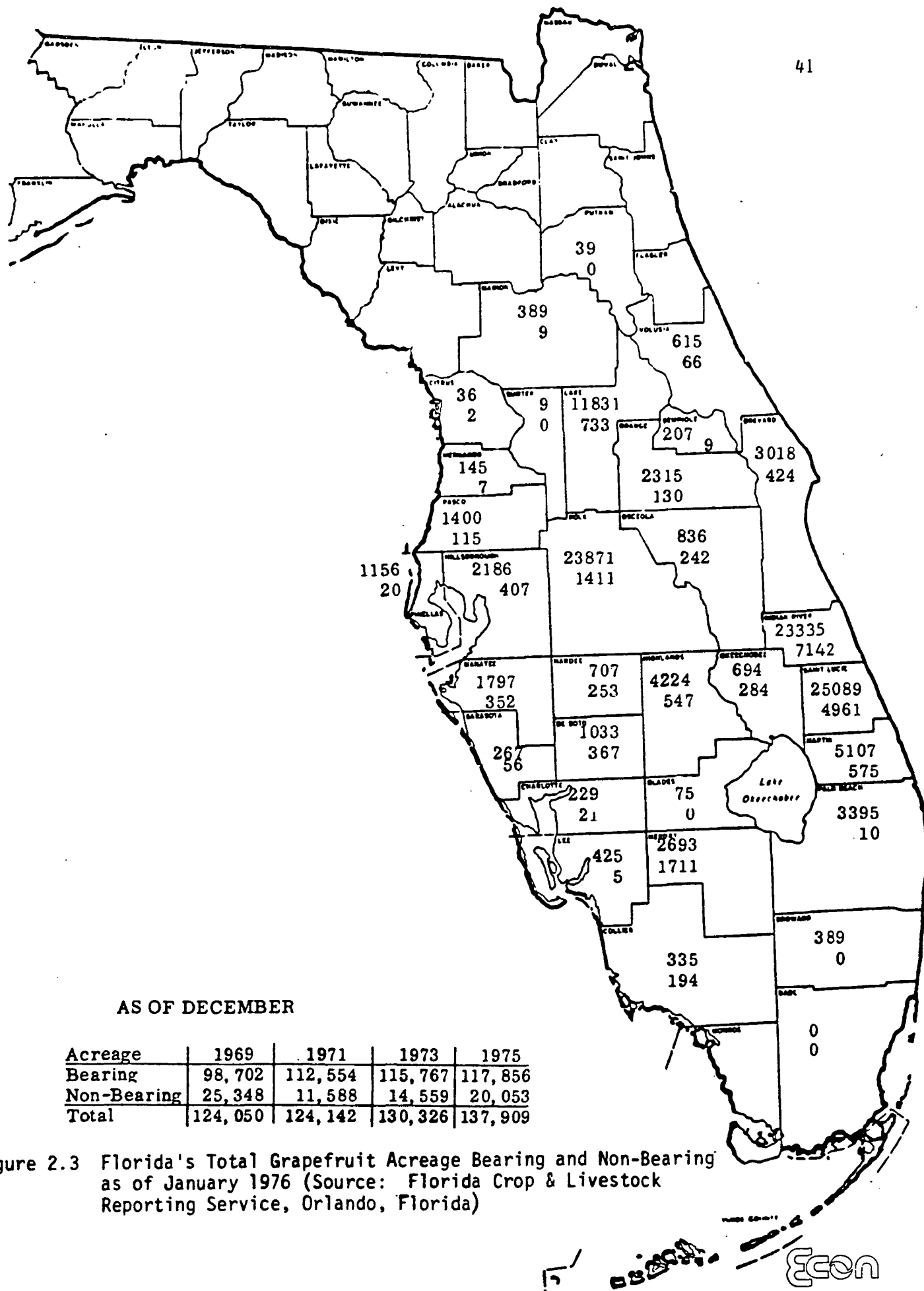


Figure 2.3 Florida's Total Grapefruit Acreage Bearing and Non-Bearing as of January 1976 (Source: Florida Crop & Livestock Reporting Service, Orlando, Florida)

As already stated, Florida is a major citrus-producing region in the United States. Florida produced 79.3 percent of the U.S. oranges (8,406,000 tons out of 10,595,000 tons) and 72.3 percent of the U.S. grapefruits (2,190,000 tons out of 3,029,000 tons) in the 1976-77 season as reported by Florida Crop & Livestock Reporting Service.

Citrus is harvested from October to July with about half of the total crop being harvested by the end of April. The early and mid-season oranges (about 54.5 percent of all orange production) are picked earlier in the season and the valencia oranges (about 45.5 percent of all orange production) are picked late in the season. The total Florida production of oranges, grapefruits and specialty fruits (tangerines, honey tangerines, temples and tangelos) for the seasons 1956 through 1977 as well as its utilization, either fresh or processed (including canned, frozen, concentrate, chilled juice, etc.), and average season price per box of citrus are given in Tables 2.2 to 2.4. The estimated values of citrus production, using the given average on-tree price per box, are also presented in these tables and indicate the magnitude of the Florida citrus industry.

2.2 Historical Loss Data^{*}

The Florida citrus production is influenced by many factors, such as fruit variety, age of trees, density of planting, topographical location, type of soil, weather conditions and nutritional and cultural practices. Many of these factors are under the control of the growers. Weather, being a collection of various atmospheric conditions such as rainfall, humidity, light intensity, amount of sunshine, temperatures and atmospheric pressure, cannot be controlled. Of all

^{*} Does not include the unnecessary costs of frost protection (i.e., costs incurred for frost protection when frost was forecast but did not occur.)

Table 2.2 Florida Citrus (All Round Oranges): Bearing Acreage, Yield Per Acre, Production, Utilization, Season Average On-Tree Price Per Box and Value For Crop Years 1956-57 Through 1976-77							
Crop Year	Bearing Acreage, 1000 Acres	Yield, 1-3/5 Bu. Boxes/Acre	Utilization of Production			Price Per Box, \$	Value of Production, \$1000
			Total 1000 Boxes	Fresh 1000 Boxes	Processed 1000 Boxes		
1956-57	374.4	241	90,300	22,616	67,684	1.40	126,678
1957-58	355.6	228	81,000	17,557	63,443	2.14	174,850
1958-59	353.4	235	83,000	15,435	67,565	2.87	238,233
1959-60	370.0	237	87,600	18,890	68,710	1.96	170,057
1960-61	374.1	221	82,700	15,113	67,587	2.98	244,376
1961-62	408.7	266	108,800	19,374	89,426	1.88	203,255
1962-63	370.0	196	72,500	11,427	61,073	2.71	196,116
1963-64	388.0	141	54,900	11,939	42,961	4.44	243,935
1964-65	435.0	189	82,400	14,598	67,802	2.43	200,276
1965-66	472.0	203	95,900	15,382	80,518	1.62	155,625
1966-67	522.0	267	139,500	17,876	121,624	.94	130,526
1967-68	557.6	180	100,500	17,096	83,404	2.07	207,432
1968-69	601.6	216	129,700	13,304	116,396	1.68	218,660
1969-70	636.1	216	137,700	13,263	124,437	1.14	156,876
1970-71	667.1	213	142,300	13,962	128,338	1.46	208,146
1971-72	623.8	220	137,000	11,233	125,767	2.04	280,317
1972-73	619.6	274	169,700	12,233	157,477	1.56	265,361
1973-74	614.5	270	165,800	11,090	154,710	1.47	244,691
1974-75	610.4	284	173,300	13,393	159,907	1.62	280,350
1975-76	596.4	304	181,200	11,730	169,470	2.10	379,692
1976-77	594.3	314	186,800	8,878	177,922	1.41	263,319

*Source: Florida Crop and Livestock Reporting Service, Orlando, Florida.

bioclimatic factors influencing citrus production, freezing temperatures result in the heaviest losses in the citrus-producing regions.

To illustrate the magnitude of the economic impact of a severe freeze on Florida's citrus industry, the damages, to the crop as well as to the citrus-bearing trees, caused by the freeze in the 1962-63 season are considered. The most severe freeze of the century, * prior to the 1976-77 season, caused temperatures to drop to 8°-11°F in Suwannee and Alachua counties and to 25°F as far south as Callier and Palm Beach counties on the mornings of December 13 and 14, 1962. The economic losses were staggering. The total loss was 50 million boxes of citrus* (32 percent of 1961-62 production of 152 million boxes), with an additional 50 million boxes of fruit having to be salvaged as concentrate. Furthermore, the freeze reduced the yield of concentrated juice obtained from the processed fruit.

*Johnson, W. O., Minimum Temperatures in the Agricultural Areas of Peninsular Florida, Summary of 30 Winter Seasons 1937-67, IFAS Publication No. 9, 1970, University of Florida, Gainesville.

Table 2.3 Florida Citrus (All Grapefruit): Bearing Acreage, Yield Per Acre, Production, Utilization, Season Average On-Tree Price Per Box and Value for Crop Years 1956-57 Through 1976-77

Crop Year	Bearing Acreage, 1000 Acres	Yield, 1-3/5 Bu. Boxes/Acres	Utilization of Production			Price Per Box, \$	Value of Production, \$1000
			Total 1000 Boxes	Fresh 1000 Boxes	Processed 1000 Boxes		
1956-57	112.4	333	37,400	18,347	19,053	.89	33,331
1957-58	95.0	327	31,100	14,704	16,396	.98	30,476
1958-59	94.0	374	35,200	16,639	18,561	1.04	36,552
1959-60	92.3	330	30,500	16,192	14,308	1.05	32,043
1960-61	92.5	342	31,600	15,886	15,714	.96	30,138
1961-62	94.0	370	34,800	17,991	16,809	.67	23,498
1962-63	88.0	341	30,000	14,038	15,962	1.24	37,146
1963-64	83.0	317	26,300	14,719	11,581	2.24	59,147
1964-65	84.0	380	31,900	15,846	16,054	1.47	46,892
1965-66	86.0	406	34,900	15,077	19,823	1.36	47,471
1966-67	87.0	501	43,600	17,281	26,319	.74	32,393
1967-68	87.5	376	32,900	14,702	18,198	2.01	66,317
1968-69	91.2	438	39,900	14,067	25,833	.98	39,011
1969-70	98.7	379	37,400	14,262	23,138	1.70	63,526
1970-71	108.3	396	42,900	14,960	27,940	1.91	81,514
1971-72	112.6	417	47,000	17,039	29,961	2.32	108,991
1972-73	114.6	396	45,400	17,046	28,354	2.08	94,635
1973-74	115.7	416	48,100	18,731	29,369	1.66	79,879
1974-75	115.4	386	44,600	18,797	25,803	1.72	76,367
1975-76	117.9	416	49,100	20,369	28,731	1.38	67,650
1976-77	119.3	432	51,500	16,393	35,107	1.35	69,309

*Source: Florida Crop and Livestock Reporting Service, Orlando, Florida.

Table 2.4 Florida Citrus (Specialty Fruit): Bearing Acreage, Yield Per Acre, Production, Utilization, Season Average On-Tree Price Per Box and Value for Crop Years 1956-57 Through 1976-77

Crop Year	Bearing Acreage, 1000 Acres	Utilization of Production			Price Per * Box, \$	Value of Production, \$1000
		Total 1000 Boxes	Fresh 1000 Boxes	Processed 1000 Boxes		
1971-72	69.4	13,700	6,448	7,252	2.17	29,712
1972-73	70.4	12,100	6,443	5,657	2.04	24,764
1973-74	69	13,300	6,343	6,957	1.91	25,341
1974-75	69.3	14,750	7,496	7,254	2.07	30,608
1975-76	65.8	16,450	8,258	8,192	2.15	35,378
1976-77	65.1	13,250	6,139	7,111	1.65	21,844

*The weighted average season prices of temples, tangerines, honey tangerines & tangelos.

Source: Florida Crop & Livestock Reporting Service.

Prior to the freeze, a yield of 1.55 gallons of concentrate per box was estimated for that part of the total orange crop intended to be used for the frozen concentrate orange juice. The actual yield was 1.09 gallons of concentrate per box.* Besides the loss to the crop, the trees sustained damage as well. About 7 to 10 million trees were killed.

Not only was the 1962-63 citrus production very low (106 million boxes) but the next season (1963-64) was also severely affected due to the loss of trees, and production was even lower (92 million boxes) than in the 1962-63 season. It wasn't until 1966-67 that recovery in Florida was sufficient for total citrus production to exceed the level of the 1961-62 season. Citrus production for the United States and Florida is shown in Figure 2.4 for crop years 1951-52 through 1976-77. The effect of frosts and freezes on citrus production can be easily observed.

During the 1976-77 winter season the cold wave of January 17-20 brought temperatures in the low 20s for several hours duration throughout the Florida citrus-producing districts (see Figure 2.5). In some areas the temperature was in the teens and it was snowing in Miami Beach. It was reported by the Crop Reporting Board of USDA in February 1977 that the production prospects for oranges were off by 9 percent and those for grapefruit by 16 percent. In April the orange production was estimated at 192 million boxes, 6 percent above last year's production. However, continued dehydration of freeze-damaged fruit further reduced the yield of frozen concentrated orange juice per box, with the actual yield being 1.07 gallons per box compared with the January 1 prefreeze projection of 1.29 gallons per box (which was also the average of 1975-76 crop year). The April estimate of total grapefruit was for approximately the same yield as that of

* Florida Citrus Commission, Two Days in December, a report on the Florida Freeze of 1962, Lakeland, Florida.

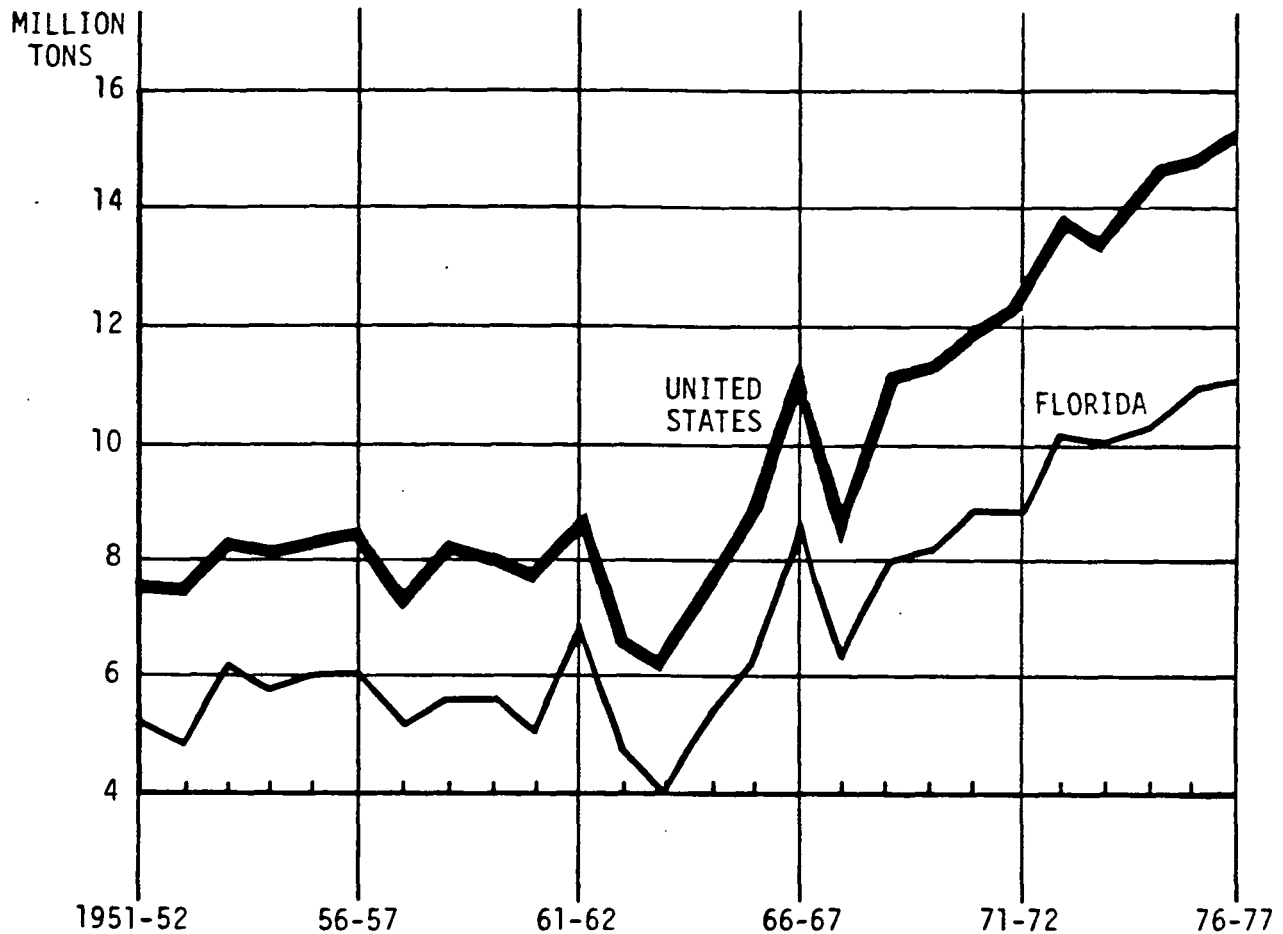


Figure 2.4 Principal Citrus Fruits: Production for United States and Florida, Crop Years 1951-52 Through 1976-77

the previous year. The total physical losses, as of the end of harvesting season were 33.81 million boxes of citrus, not including lemons and limes; of this, 15.93 million boxes of fresh fruit and 17.88 million boxes of fruit for processing were lost.

Table 2.5 summarizes the freezes which have occurred since 1939, indicating the estimate of the citrus crop (oranges and grapefruits only) and the final production achieved in each season. The original USDA estimates of citrus production (by variety) are compared with the actual production in Table 2.6. The influence of freezing temperatures during the winter season on citrus crop production is readily apparent.

Table 2.5 Historical Freezes Which Influenced Citrus Crops,
1939-40 Through 1976-77 Seasons.

Seasons	Description of Freeze	Monthly Production Estimate ^a (10 ⁶ boxes)	Final Production (10 ⁶ boxes)
1939-40	During the dates of January 27, 28 and 29 temperatures of 15° and lower covered the upper one-third of the state. Temperatures in the low 20's covered the remainder of the state.	na ^b	26 ^c
		na	16 ^d
1946-47	On February 6 temperatures were in the low 20's in the North and in several pockets throughout the State. Temperatures in the mid 20's covered the remainder of the state except along the southern coast.	na	54
		na	29
1957-58	Freezing temperatures occurred on December 12 and 13 in the northern and central areas of the state. On February 4 and 5 temperatures in the mid 20's covered the entire state.	102	82
		36	31
1962-63	A "big" freeze in all areas of the state during the period December 11-15 produced the "greatest citrus loss in history." Below normal temperatures occurred during each month of the winter season.	120	74
		38	30
1969-70	Temperatures of 28° and lower occurred January 7-11 which damaged fruit in the northern and central districts. Temperatures of short duration in the mid 20's occurred in the northern and central districts on February 4 and caused minor damage. Loss of fruit due to the freeze was minimum, but juice yield was reduced.	140	143
		37	37
1970-71	Freezing temperatures and heavy frost occurred on November 25 in all agricultural areas except the lower east coast. Heavy fruit and wood loss occurred in Hillsborough County on January 20 and 21 as severe freeze in the upper teens covered all areas except the lower east coast.	175	147
		49	43
1976-77	One of the major freezes of the century occurred January 16-21. Snow fell in Miami for the first time in recorded weather history. Minimum temperatures in the teens were noted on the morning of January 18 with durations of 26°F and below for 6 to 12 hours. Very heavy frost was seen in the Everglades that night. Even colder air was on its way southward from Canada. On the next day, January 19, high temperatures were only in the 30s in northern and central Florida, and 40s in southern Florida, the lowest maximum temperatures ever recorded. On the night of January 19-20, temperatures remained in the 20s throughout all of Florida for many hours. 98 percent of oranges surveyed by F.C.&L.R.S. on January 20 had ice, with 48 percent showing hard ice to the center of the fruit.	217	184
		58	52

^aRefers to the monthly estimate of the Florida Crop and Livestock Reporting Service which preceded the first freeze of the season, providing the freeze occurred prior to the 10th of the month. For example, if a freeze occurred prior to January 10, the December estimate is listed. If the freeze occurred after January 10, the January estimate is listed.

^bNot available.

^cOranges

^dGrapefruit

Source: Florida Cannery Association, Florida Citrus Mutual and Florida Crop and Livestock Reporting Service.

Table 2.6 Original Government Estimates For Seasons 1969-70 Through 1976-77 As Compared With Season Total Production
(in thousand of boxes) 1/

Season	ORANGES				GRAPEFRUIT					
	* Early & Midseason		Valencias		Seeded		Seedless			
	Original Estimate	Actual Production	Original Estimate	Actual Production	Original Estimate	Actual Production	Original Estimate	Actual Production		
1969-70 Over & Under	87,000 +8,900 Comment: Severe cold January 7,8,9,10,11. Some damage in northern and central districts. Rainfall for season adequate to some excess during winter, dry during April and March.	78,100	62,000 -2,800	64,800	10,000 + 500	9,500	27,900 + 900	27,000		
1970-71 Over & Under	100,500 +13,400 Comment: Severe cold Nov. 25, Jan. 20-21, Feb. 8. Freeze damage severe in many areas. Near drought conditions over central & southern areas during most of the year.	87,100	74,000 +13,800	60,200	15,000 +3,200	11,800	34,000 +2,900	31,100		
1971-72 Over & Under	73,000 -1,100 Comment: Hardest winter on record. No freeze damage, no hurricanes. Rainfall was spotty.	74,100	64,000 -4,200	68,200	10,000 - 900	10,900	33,000 -3,100	36,100		
1972-73 Over & Under	92,000 +2,000 Comment: No freeze, no hurricanes. Rainfall ample from June to date.	90,000	82,000 +2,300	79,700	11,000 + 800	10,200	34,000 -1,200	35,200		
1973-74 Over & Under	93,000 +1,100 Comment: No major cold weather, severe dry weather, January through May. No hurricanes through August. More than ample rainfall June, July and August.	92,100	72,000 -1,700	73,700	10,500 + 500	10,000	37,500 - 600	38,100		
1974-75 Over & Under	102,500 + 600 Comment: Generally mild winter, severe drought first five weeks, no hurricanes. Ample rainfall during June, July and August.	101,900	77,000 + 300	76,700	9,500 +2,300	7,200	35,500 +1,900	37,400		
1975-76	103,500 - 800 Comment: No hurricanes. No major cold weather. From extremely dry first of season to ample rainfall rest of season from June to date.	104,300	74,000 -8,400	82,400	9,000 +1,200	7,800	41,000 - 300	41,300		
1976-77	126,700 -7,900 Comment: No hurricanes. Freeze January 18, 19th. Snow fell in some sections of Central Florida. Severe drought in various citrus countries during April, May & June. Very wet during July and August.	118,800	88,000 +16,200	71,800	10,000 - 900	9,100	48,000 +3,500	51,500		
* Temples included.										
Source: Florida Citrus Mutual, Annual Statistical Report, 1976-77 Season 1/ 90 lb. oranges, 85 lb. grapefruit.										

The value of production of oranges lost due to frosts and/or freezes is illustrated as follows: It was estimated by the USDA (Table 2.6) that the total production of oranges would be 174.5 million boxes during the 1970-71 season. The actual production was only 147.3 million boxes. The loss of 27.2 million boxes of oranges can be attributed primarily to the rather severe freezes in that season. Although the increase in prices for undamaged citrus fruit after the freeze offsets the lost revenue due to freeze damage, the magnitude of losses indicates the importance of frost protection for the citrus industry.

There are additional losses in citrus production due to ice, rain, hail and hurricanes; but all these are minor compared to losses caused by freezing temperatures.

2.3 Weather Sensitivity of Citrus

There are basically two types of frosts; the advective freeze and the radiational frost. An advective freeze occurs when a mass of cold, dry air having thickness of 500 to 5,000 feet is transported from the polar regions by winds having velocity exceeding 5 mph. A cold front of dense air displaces a warmer air mass very rapidly as it moves southward. The temperature falls rather uniformly throughout the night (Figure 2.6) during the advective freeze on low grounds as well as high grounds. Pockets of warmer air remain in valleys (Figure 2.7).

A radiational frost occurs when air, soil and plants are cooled to freezing temperatures through loss of heat by radiation. The thickness of the cold air mass is between 30 to 200 feet and moves slowly with wind velocity under 3 mph. The surfaces of plants and earth exhibit a heat loss at a greater rate than the surrounding layer of air which is cooled by this radiation and, through thermal conduction, cools the subsequent layers of the atmosphere. This process results in a temperature inversion, when air temperature increases with the increasing height

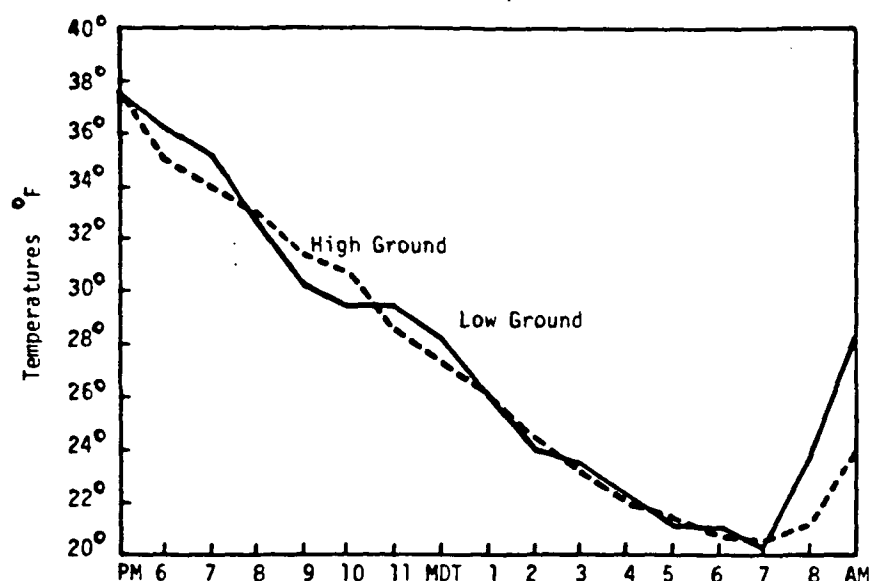


Figure 2.6 Typical Temperature Progression for Advective Freeze Indicating Little Difference in Temperatures on High and Low Ground Locations on a Windy Night (Source: Johnson, W. O., Minimum Temperatures in the Agricultural Areas of Peninsular Florida, Summary of 30 Winter Seasons 1937-67, IFAS Publication No. 9, University of Florida)

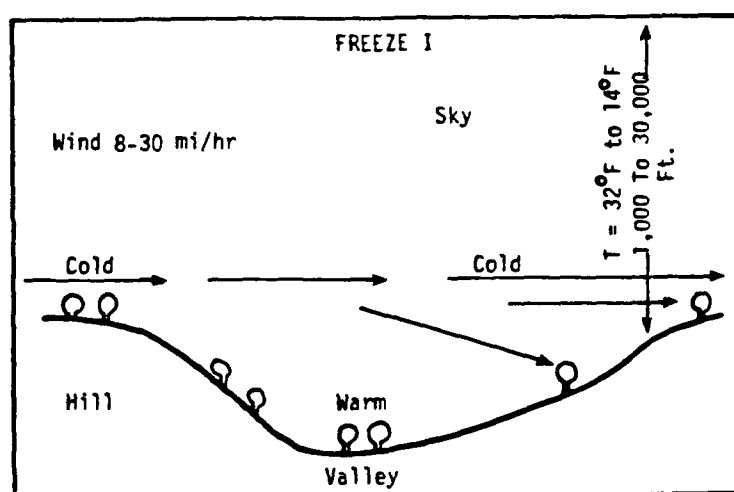


Figure 2.7 Diagram Showing Micrometeorology of a Freeze in a Hilly Country. In flat country, micrometeorology is similar to hilltop on left. (Source: Reuther, W., Editor, The Citrus Industry, Vol. III, University of California, Chapter 10)

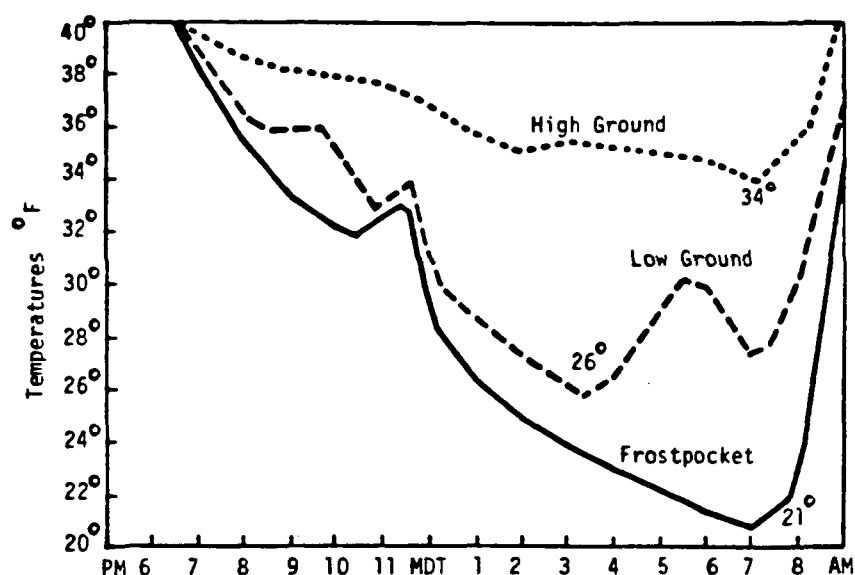
above the ground. Also, as a consequence of the thermal inversion during radiational frosts, there are higher temperatures on high grounds and lower temperatures on lower grounds (Figures 2.8 and 2.9). The cooled air is heavier than the dry air and flows down due to gravitational forces into lower elevations. If there are depressions in the sloping terrains, very cold frostpockets are formed.

An elevation difference of as little as 4 to 5 feet above a surrounding area can cause an increase of from 2° to 5°F on cold, clear and calm nights. If there is an air flow of the warmer air in a layer 10 to 40 feet above the tree tops, the rising colder air (due to the inversion) mixes with the warm air of upper layers and the resulting turbulence is often sufficient to prevent the development of radiation frosts.

A relatively high atmospheric moisture results in formation of small crystals on plants and soil, so called hoarfrost or white frost, when soil and plants are cooled to the dew point temperature.* A low atmospheric moisture, when dew point is lower than the soil and plant surface temperatures, results in black frost since the air is too dry to form crystals. Radiational frosts are characterized by calm air, clear skies and low atmospheric water vapor content.

The very damaging freeze-frost combinations occur when cold, freezing winds are replaced by calm periods of radiational frost. A typical Florida freeze may last two days. The first night is usually a cold windy advective freeze but rarely a seriously damaging one. Usually there is a little warming of the air or trees during the second day as cold air continues to move south. During the second night the wind usually falls soon after sunset and the stratifying air may reach dangerously low temperatures rather soon, especially in low areas. This is when

*The dew point temperature is the temperature at which the moisture in the air begins to condense onto leaf surface.



the greatest damage to fruit and trees is done. On the third day the wind usually shifts and begins to replace the cold air with warmer air from the ocean.

The most severe damage results when an early winter freeze is followed by a period of warm weather sufficient to initiate new growth, which in turn is followed by a second freeze in the same winter. The trees are much more susceptible to freezing temperatures because of the new growth and are then killed to the ground.

The movement of a mass of cold polar air into subtropical regions, associated with an advective freeze, results in very low air temperature--between 8°F and 28°F. The probability of occurrence of these temperatures is small in December, increases throughout January and decreases from the middle of February. The records show that several severe freeze-frost combinations occurred in late November and milder radiational frosts as late as April.

The January 1977 freeze, the worst in Florida in 15 years, followed the pattern of freeze-frost combination. The first wave of cold air entered the peninsula during the night of January 16/17 with temperatures in the upper 20s to lower 20s in central Florida. Moderate winds prevented any frost during that night but temperatures dropped to the low 20s with durations up to six hours and moderate frosts developed during the night of January 17/18. Then the massive cold wave of an advective freeze with strong winds brought along snowfalls as far south as West Palm Beach. The temperature stayed low during the day of January 19 and as the high front moved eastward out of the peninsula, winds diminished and temperatures dropped below 28°F early in the evening. The whole peninsula experienced very low temperatures, from low 20s in the north-central region (in the teens in some areas) to mid 20s in the southern region, with durations of up to 14 hours below freezing level. The most damage to the citrus crop was reported as occurring during the night of January 19/20.

2.4 The Role of the National Weather Service

2.4.1 Frost Warning System in Florida

The vulnerability of the citrus crop to the effects of freezing temperatures and the impact of an accurate and timely weather forecast have been recognized for a long time. The Federal-State Agricultural Weather Service was established in the citrus belt of Florida, with headquarters in Lakeland, in 1935 and later extended to cover the whole peninsula. The forecast bulletins issued twice a day during the frost season (from November 1 through March 31) provide the growers with an estimate of the geographic distribution of the anticipated minimum temperatures.

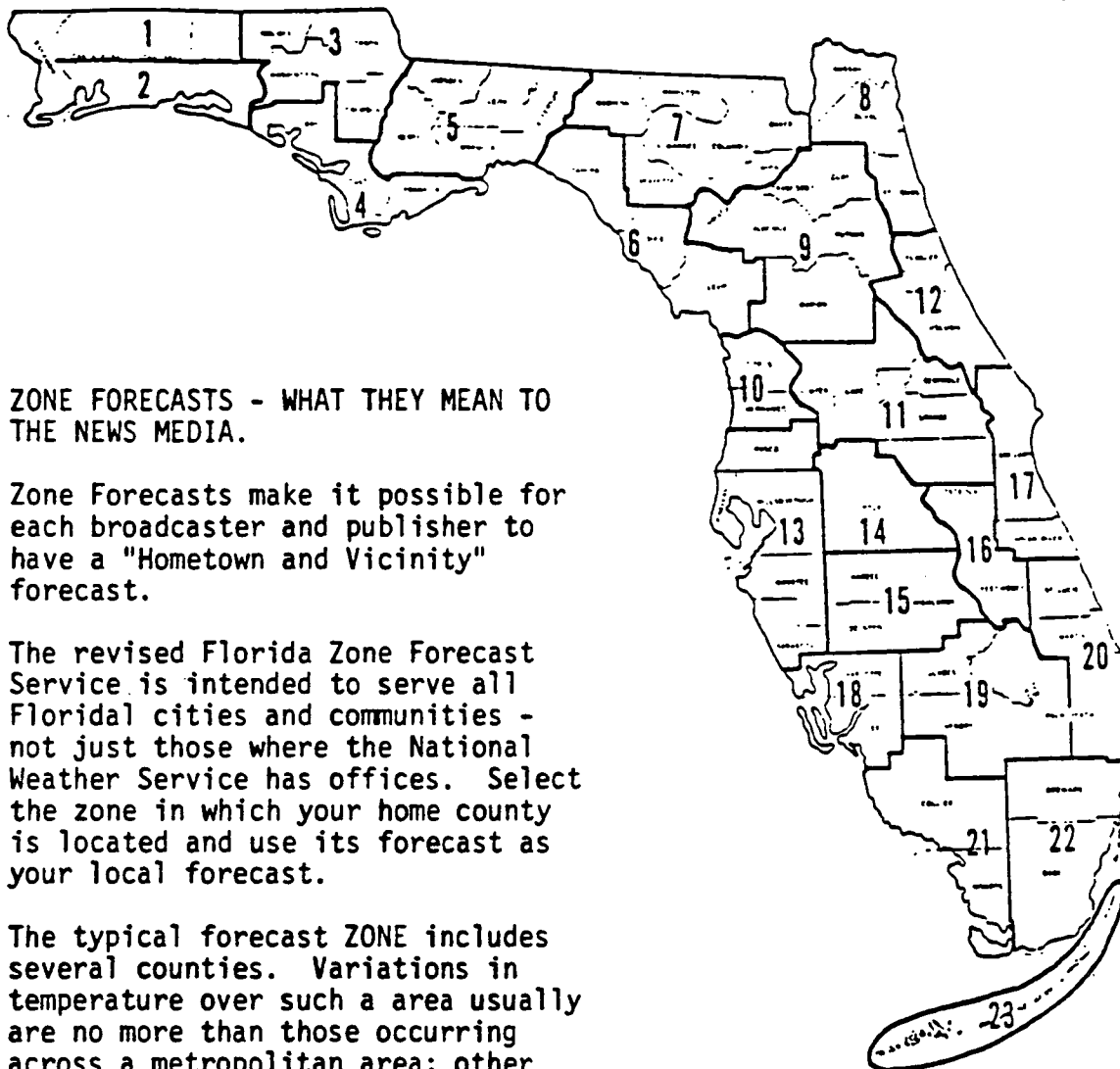
The weather forecasting function of the Federal-State Agricultural Service was incorporated into the National Weather Service, with Florida headquarters in Ruskin. The forecast zones are shown in Figure 2.10.

The minimum temperature forecast, accompanied by an outlook for the next one to three nights, and forecasts of clouds and winds are the main function of NWS Agricultural Weather Service. The other functions* are:

- a. To offer an advisory service of how to prevent damage from frost and/or freezes
- b. To provide temperature durations for key stations throughout the growing areas (these are available immediately following nights of frost damage)
- c. To compile annual reports on the general character of each season with respect to crop-weather relationship, tabulations of minimum temperatures from stations within the forecast area for selected nights, durations of temperatures below 32°F from all survey stations and comparative data and observations
- d. To study temperature and crop relationships, researching the meteorological relationship with respect to methods and equipment for frost protection.

* Operations of the National Weather Service, U.S. Department of Commerce, NOAA, NWS, Silver Springs, Maryland, 1974.

FLORIDA FORECAST ZONES
(Revised October 1, 1972)



ZONE FORECASTS - WHAT THEY MEAN TO
THE NEWS MEDIA.

Zone Forecasts make it possible for each broadcaster and publisher to have a "Hometown and Vicinity" forecast.

The revised Florida Zone Forecast Service is intended to serve all Floridal cities and communities - not just those where the National Weather Service has offices. Select the zone in which your home county is located and use its forecast as your local forecast.

The typical forecast ZONE includes several counties. Variations in temperature over such a area usually are no more than those occurring across a metropolitan area; other weather differences within a zone are usually little different. The Zones shown in the map on this page are revised as of October 1, 1972 to better meet the needs of the using public.

Figure 2.10 Map Showing Florida Forecast Zones as Used by the National Weather Service (Source: National Weather Service, Southern Region Headquarters, Fort Worth, Texas)

2.4.2 Frequency and Dissemination of Frost Forecasts

Currently (prior to the start of the 1978-79 frost season) the official weather forecast by the National Weather Service (NWS) is made four times a day, at 6:00 a.m., 10:15 a.m., 4:15 p.m. and 10:15 p.m. The early morning forecast at 6:00 a.m. is a temperature outlook for the next 24 hours for the entire state. No detailed meteorological data are forecast.

The 10:15 a.m. forecast is the next important forecast of the day. The weather prediction is based on the data obtained from the meteorological soundings, the readings of government thermometers throughout the state (about 200 thermometers), and the additional data obtained from the weather stations, such as the heat flux from the earth and radiational losses. The forecast begins with a preamble, for the whole of peninsular Florida, which gives qualitative indications about temperature, the minimum temperature and its approximate time of occurrence, wind direction and wind speed, and finally information on any possible temperature inversion. The preamble is followed by detailed temperature forecasts expressed as a 4°F interval for each forecast zone.

The 4:15 p.m. forecast is an update of the 10:15 a.m. forecast, based upon the additional temperature readings of the government thermometers. There is no input from the meteorological soundings (they are launched only twice a day). This forecast rarely deviates from the 10:15 a.m. forecast. Typical 10:15 a.m. and 4:15 p.m. forecasts are presented in Figures 2.11 and 2.12, respectively.

Finally, the 10:15 p.m. forecast is an update of the 4:15 p.m. forecast and includes changes in weather problems that may occur. Normally, if the 4:15 p.m. forecasted temperatures are above 28°F, the 10:15 p.m. forecast is not given.

There are several means of forecast dissemination, such as teletype, public radio and telephone. Typically, a grower receives the official NWS forecast on his own teletype, which costs him approximately \$100/month for the teletype line.

MANN
ZCZC
FXUSS RWRB 281515

PENINSULAR FLORIDA FARM AREA MINIMUM TEMPERATURE FORECAST
ISSUED AT 10:15 AM EST WEDNESDAY JAN 23 1975
NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FLORIDA

FOR TONIGHT FROST AND FREEZE WARNING ALL ZONES
CLEAR AND COLD ALL ZONES. TEMPERATURES WILL DROP STEADILY DURING THE NIGHT
WITH LOWEST TEMPERATURES NEAR SUNRISE. WINDS LIGHT AND VARIABLE
WITH PERIODS OF CALM AFTER MIDNIGHT.

LOWEST TEMPERATURES

ZONES 6 7 8 22 TO 26 FROST

ZONE 9 24 TO 28 FROST

ZONES 10 11 12 13 14 15 16-28 TO 32 POCKETS AND COLDER LOCATIONS
26 TO 23 WITH FROST.

ZONE 17 32 TO 36 SCATTERED FROST

ZONES 18 19 21 34 TO 40 PATCHY FROST PACKLANDS.

OUTLOOK FOR THURSDAY NIGHT...NOT AS COLD. CHANCE OF FROST
AGAIN CENTRAL AND NORTH PORTION.

Figure 2.11 Typical 10:15 a.m. Forecast

FAUSB RWRB 28211

PENINSULAR FLORIDA FARM AREA MINIMUM TEMPERATURE FORECAST
ISSUED AT 4:15 PM EST WEDNESDAY JANUARY 28 1976
NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FLORIDA

FROST AND FREEZE WARNINGS

TONIGHT...CLEAR AND COLD ALL ZONES. TEMPERATURES FALLING STEADILY
DURING THE NIGHT WITH LOWEST TEMPERATURES TO OCCUR NEAR SUNRISE.
LIGHT AND VARIABLE WINDS WITH PERIODS OF CALM AFTER MIDNIGHT.

LOWEST TEMPERATURES

ZONES 6 7 20 TO 24 FROST

ZONES 8 9 24 TO 28 FROST

ZONES 10 11 12 26 TO 30 WITH 24 TO 26 COLD POCKETS
AND MUCKLANDS. FROST

ZONES 13 14 15 16 28 TO 32 WITH 26 TO 28 COLD POCKETS
AND MUCKLANDS. FROST

ZONE 17 32 TO 36 SCATTERED FROST

ZONES 18 19 21 33 TO 37 SCATTERED FROST

ZONES 20 22 35 TO 40 PATCHY FROST

TEMPERATURE OUTLOOK...NOT AS COLD. CHANCE OF SCATTERED FROST
NORTHERN ZONES FRIDAY MORNING.

Figure 2.12 Typical 4:15 p.m. Forecast

The official NWS forecast is rebroadcast by public radio stations and also disseminated via radio by 24-hour continuous weather broadcasts, updated every six hours, with taped messages repeated every 4 to 6 minutes. Many growers have special receivers which enable them to listen to this VHF-FM radio broadcast at frequencies of 162.55 MHz and 162.40 MHz.

2.4.3 Informal Non-NWS Forecasts

Besides these public means of dissemination, the growers can obtain the latest forecast by calling the unlisted telephone number of the NWS Office at Ruskin or the Federal-State Agricultural Weather Service at Lakeland and listening to the recorded official NWS forecast. This is especially beneficial to smaller growers who cannot afford to have the teletype service. The growers also communicate extensively among themselves and with the county extension agents and exchange information about temperatures obtained from their thermometers. There are no official (by NWS) temperature readings of government thermometers after dark, only the unofficial data provided by the growers. Importantly though, meteorologists of the Federal-State Agricultural Weather Service give an informal "localized" forecast, which is based on the above unofficial data and information from NWS, for growers' particular regions, by phone. Besides the temperature range, they also provide the probabilities with which these temperatures will occur. This type of constant communication usually lasts until 1:00 a.m. on a cold night. By that time the growers have decided whether to initiate a frost protection action or have assumed that the temperature will not become low enough to cause any damage.

2.4.4 The Improved Weather Forecast

Currently (i.e., prior to the introduction of satellite-measured temperature data and computerized temperature forecasting models) weather forecast accuracy is dependent, to a large extent, upon the forecaster's experience and knowledge of local conditions. All data available to a meteorologist, whether from meteorological sounding or temperature readings from ground stations, is in discrete sets. Approximate temperature maps are generated and then combined in the forecaster's mind, based purely on his own experience, into a more or less continuous picture in time and space, incorporating other factors which played important roles in this highly subjective forecasting process. It requires a number of years of experience to master all of the intricate peculiarities in topography and other factors in order to make effective and accurate forecasts. As many of the experienced meteorologists retired from NWS, they were replaced, in some cases, by younger forecasters who do not have the necessary experience.

It was anticipated that, starting with the 1977-78 frost season, the utilization of satellite-measured temperature data in combination with computerized forecasting models would result in improved accuracy of weather forecasts and knowledge of actual temperature distributions across the state of Florida. The satellite data, together with computer forecasting models, was expected to help remove the human factor from weather forecasting and, therefore, to make the forecast more independent of the forecaster's capability. It was expected that this, in turn, would have a direct impact on improving frost protection decisions, with reduced protection costs and crop losses. Further, it was hoped that more accurate meteorological forecasts would lead to improved marketing strategies for the citrus growers. The temperature data measured remotely by the SMS/GOES satellite began to be available to the NWS forecasters during the 1977-78 frost

season, although not at the level previously anticipated. The temperature data was transmitted to the NWS office in Ruskin and processed with an image interpreter. When operating correctly, the system has the capability to provide a continuous map of meteorological events in time as well as space, since temperatures can be remotely measured every 30 minutes. Although the electronics were put into operation on a number of cold nights during the 1977-78 frost season, technical problems prevented the systematic use of the satellite data. Instead, the meteorologists used the satellite pictures informally both as an additional input to their forecasting process and as a check on the forecast prepared by the usual method. It is expected that during the 1978-79 frost season, the Florida NWS will make a more decisive step toward minimizing the subjectivity of weather forecasts, through expanded use of the satellite data.

Another important improvement in the NWS weather forecast capability will be the use of the temperature forecast model developed by the University of Florida which draws upon the satellite-measured temperature data. Although the model was originally slated for extensive testing during the 1977-78 frost season, technical problems forced a postponement in the application of the model to real-time forecasting situations. Together with the interpreted pictures, the forecast model is expected to enable the NWS to significantly improve its frost warning system. When the model and the new temperature map system are made fully operational, one of the first results of this improved data base for forecasting will be the narrowing of the forecasted temperature range from 4°F to 2°F. This narrower range of temperatures would be extremely helpful during "wait and watch" nights when the forecasted temperature is in a borderline region, and the growers must decide either to take a protective measure or to leave this grove unprotected.

It was assumed that the 1977-78 winter season would be a transitional one, with NWS forecasters at Ruskin learning to use the new systems. Because of the unplanned delays, the forecasters did not make as extensive use of, or become as familiar with the operational use of the new technology as had been expected. Experience was gained with the system in nonoperational situations. However, the satellite-measured temperature data and the forecasting model will be used extensively in future years, beginning with the 1978-79 season. It seems appropriate, therefore, that grower information gathered during both the 1976-77 and 1977-78 seasons should be used as control group data, and that any data gathered in subsequent years should be considered as test group data.

2.5 Frost Protection Methods

The research in the areas of environmental physiology^{*} indicates that there is a dynamic energy exchange between the plant's tissues and its environment which, together with other factors such as air temperature, wind velocity, relative humidity, soil moisture and fertility, regulates the process of growth and development as well as the conditions during frosts and freezes. (See Appendix A.) The decision to use or not to use a particular frost protection method is influenced by these factors and additional natural features in and around a grove. These are: local topography and possibility of thermal inversion, windflow paths, type and chemical state of soil, temperature of the water used for irrigation or sprinkling, temperature of ground, availability of cover crops and windbreaks, proximity of large bodies of water and other citrus orchards, and dormancy status of trees (dormant trees are less susceptible to frost damage).^{**}

^{*} Reuther, W., editor, The Citrus Industry, Vol. III, University of California.

^{**} Cooper, W. C., R. H. Young and F. M. Turrell, Microclimate and Physiology of Citrus: Their Relation to Cold Protection, Agri. Sci. Rev., 2(1):38-50, 1964.

The heat stored in soil is released during the cold nights. The amount of heat radiated from moist sandy soil is greater than from other types of soil because sandy soils have greater heat capacity and thermal conductivity, and they do not cool the surrounding layer of air extensively.

The proximity of lakes and reservoirs to orchards is most beneficial during advective freeze nights. Much of the heat stored in these large bodies of water during the warm period, because of water's large heat capacity and thermal conductivity, is then picked up by the air in passing over the water surface and is recovered by leeward trees in the grove.

All the terrestrial heat from the trees, soil and water is absorbed by clouds, if it is cloudy, and almost three-quarters is radiated back to earth. As a result of this fact, a radiation frost does not normally develop when the air is calm and there are clouds or fog, even if the temperature is low enough to cause frost when the sky is clear.

The most common protective system of a citrus grove against freezing temperatures consists of a combination of the two principal methods of frost protection: using heaters to generate heat, and using wind machines to create turbulence which redistributes heat in and above the orchard.

Heaters have proved to be the most efficient in the heating of citrus orchards. Oil heaters are very effective in combating long advective freezes. Most heaters currently in use have a capacity to burn all night (up to 6 hours) without refueling, are relatively easy to light under all weather conditions and satisfy environmental standards (do not produce excessive smoke). Return stack, jumbo cone and lazy flames are the most commonly used heaters in Florida.

Heat released from heaters by burning fuel is in convective and radiational forms. Convective heat, in the form of hot gases and heated air, is distributed

throughout the grove by movement of the air. Radiational heat is released from the flame and heater stacks. Trees close to heaters are warmed by radiant heat rather than by convective heat. A heater is more effective with the increasing percentage of radiational heat it can produce.

The effect of heaters is greatly reduced by radiational losses of heat directly to the sky from the top of a grove and by light hot air, warmed by convectional heat, being blown away by the wind. The total losses from an unprotected citrus grove on cold nights range from 0.9 to 1.8 million BTU/acre/hour.* Because of the above stated losses, the total heating system should provide 3 to 5 million BTU/acre/hour to adequately protect an orchard.

There are several other factors which influence the effectiveness of cold protection by heaters, the most important of which is wind. Since the hot air is blown away by wind, protection is greatly reduced on windy nights. Windbreaks reduce the velocity of wind and increase heating efficiency. Border areas of an orchard require additional heaters for good protection because of an inflow of cold air. The heat distribution throughout a grove should be as uniform as possible. The effect of wind is reduced for larger groves since the trees tend to reduce the wind speed. Size of trees also plays an important role. Large trees resist the wind and their canopies are also large and therefore intercept more radiant heat.

Refueling of heaters represents a problem during advective freezes of long duration (a heater can hold up to 9 gallons of fuel). Normally, insufficient laborers are available to distribute the fuel. Some growers, therefore, use more heaters than necessary so they have enough fuel for two nights. A system with permanent

* Gerber, J. F. and J. D. Martsolf, Protecting Citrus from Cold Damage, AESUF, Circular 287, 1966.

oil supply pipes eliminates this problem but requires a large capital expenditure and is therefore used primarily in nurseries.

As stated earlier, a wind machine redistributes the heat in the layers of air by producing enough turbulence to break up the temperature inversion of the air and mixing its warm and cold components. This mixture is then transported across the orchard and the cold air is pushed out until a pressure equilibrium is set up between the mixture in the orchard and cold dense air outside the orchard. One wind machine (30 brake horsepower-bhp) can protect 3.5 to 6 acres. Several wind machines operating together provide greater temperature response per machine than one. Large machines (90 bhp and more, using two propellers) also provide greater protection in low spots.

The efficiency of wind machines depends on the thrust and reach of propellers in relation to the power source. The thrust and reach decreases with decreasing temperatures as air density increases and viscosity decreases. The wind machine's reach on a very cold night is about 50 percent of the reach on a warm day. Wind machines offer advantages in cold protection because they minimize labor requirements, require less refueling and less fuel storage than heaters, are permanently located in the grove, have a low operational cost per acre, and do not produce smoke and air pollution. These advantages must be weighed against the disadvantages of rather high capital costs and the failures of the wind machine to provide adequate cold protection under all conditions.

Additional protection may be provided by a combination of wind machines and heaters. The heaters not only give added protection at lower temperatures, but also increase the effectiveness of wind machines.

There are other methods of cold protection, such as utilizing the proximity of lakes and reservoirs, creating windbreaks, providing proper air drainage, and also

irrigation, sprinkling, chemical spraying, insulation of trees, and manmade fog. To a large extent, these methods are either not available or not used, for economic reasons, in commercial citrus production. A comparison of major grove-heating systems is presented in Table 2.7.

Overhead water sprinkling as a frost protection measure has several advantages. The sprinkler system can be started and stopped easily, the labor cost is minimized and the sprinklers are used for regular irrigation. The system must be capable of supplying enough water so there is a continuous supply of heat obtained from freezing of water drops. It is, however, not efficient against severe freezes.

Recently the new micro-jet nozzles have become very popular since they do not freeze in very cold temperatures and provide a very fine spray of water which absorbs the cold air and thus effectively protects the trees.

2.6 Frost Protection Decision Process

2.6.1 Factors Influencing Grower's Decision to Protect

The decision of a grower to initiate protective action against freezing temperatures, assuming that they are forecasted for a coming night, depends upon a number of factors which have to be considered simultaneously. Besides meteorological factors such as current and forecasted temperature and its duration, wind velocity, humidity and cloud movement, protection decisions take into account such factors as the grove topography, variety of citrus grown and its use as fresh or processed product, market prices, previous crop damage, the grower's feeling on acceptable risk.

The geographical location, topology, the local microclimate and other factors influence the need for and the selection of frost protection technology. Wind machines and heaters could be used independently as well as in combination. The use and function of both wind machines and heaters have already been described.

Table 2.7 A Comparison of the Important Grove-Heating Systems

System	Radiant Heat	Effectiveness				Air Pollution	Efficiency (BTU/Degree Temp. Rise)	Costs		
		With Low Ceiling	With High Ceiling	As Border Heater	Fixed Capital			Fuel	Labor	
Lard pail*	Poor	Good	Poor	Good	Poor	Poor	Good	Fair	Fair	
Lazy Flame	Fair	Good	Poor	Fair	Poor	Fair	Fair	Good	Fair	
Jumbo cone	Good	Excellent	Fair	Poor	Good	Good	Poor	Good	Fair	
Return stack (gas or oil)	Good	Excellent	Fair	Poor	Good	Good	Poor	Good	Fair	
Pipeline	Fair	Excellent	Poor	Good	Fair	Fair	Poor	Good	Good	
Wax candles	Poor	Good	Poor	Good	Poor	Poor	Excellent	Poor	Poor	
Wind machines	Poor	Excellent	Poor	Poor	Excellent	Excellent	Poor	Excellent	Excellent	
Wind machines and heaters	Fair	Excellent	Good	Good	Good	Good	Poor	Excellent	Good	
Petroleum coke bricks	Excellent	Excellent	Excellent	Excellent	Good	Good	Excellent	Poor	Fair	
Heaters and petroleum coke bricks	Good	Excellent	Excellent	Excellent	Good	Good	Fair	Good	Fair	
Wind machines and petroleum coke bricks	Fair	Excellent	Good	Excellent	Good	Good	Poor	Excellent	Good	

* Not acceptable where smoke controls exist.

Source: Albrecht (1967). The Citrus Industry Vol. III, W. Reuther, editor, University of California

The combined use of both of these methods is the most effective when the temperatures are low, and/or inversions are very weak. The heaters provide additional heat which is then mixed throughout the grove by wind machines. Fewer heaters per acre are needed (approximately 15 to 25) in this combined system.

The exact level of freezing temperatures and their durations seem to be critical as far as the damages to the fruit and trees are concerned. It was reported* that leaf temperatures of 20°F and colder kill 100 percent of mature leaf tissue, while temperatures in the range of 20° to 21°F can be expected to kill between 50 to 70 percent. A 22°F reading was found to kill only 5 percent, and temperatures in the range of 23° to 24°F killed only 1 percent. Commercial growers tend to consider a hard freeze (one resulting in fruit loss and/or tree damage) to be characterized by temperatures equal to or less than 26°F for four or more hours (see Table 2.8). Therefore, as protection measures, wind machines are

Table 2.8 Freezing Point for Citrus (°F)			
Degrees of at least two hours duration		Degrees of at least two hours duration	
Small green oranges	28.5	Tender growth	27.0
Green oranges and grapefruit	27.5	Dark green growth	24.0
Half ripe orgs. & grapefruit	27.5	Buttons	24.0
Full ripe orgs. & grapefruit	27.0	Open bloom	30.0
Tangerines	29.5		
Source: The National Weather Service Office of State Climatology, Lakeland, Florida.			

* Hendershott, C. H., The Responses of Orange Trees and Fruits to Freezing Temperatures, American Society for Horticultural Science Proceedings, Vol. 80 (1962), pp. 247-254.

normally started when air temperature drops to 32°F and a duration of two or more hours at this or lower temperature is forecasted, and the air mixing started several degrees before critical temperatures, damaging to fruit and leaves, are reached. The heaters are normally lit when the temperature readings are 26°F. As it was stated above, these temperatures are typical and actual decision points vary greatly among the growers.

Some varieties of citrus are more sensitive than others to freezing temperatures and therefore require greater protection. Another important consideration linked to citrus variety is the date of fruit maturity. Some varieties mature during the winter months and, as a result, could be harvested immediately after a damaging frost. On the other hand, if the spring-harvested varieties are damaged, the losses are more severe.

Finally, the intended final use of the crop, whether it be for fresh fruit or processed concentrate, greatly influences long-term protection methods. Certain varieties of citrus, such as honey tangerines or temple oranges, are much more valuable as fresh fruit and, therefore, it is desirable to protect this valuable crop because of the substantial difference in market price between the fresh fruit and processed product.

In addition to these influences, the grower in the short run is always aware of fresh fruit spot prices, concentrate futures prices, his current debt situation and the price of fuel. These factors could be said to influence the grower's feelings on acceptable risk. What is unknown or at best uncertain to the grower during the crucial nightly decision making is the weather. In order to illustrate the interplay between what is known to the grower, that is location, variety, final use, acceptable risk and the weather, an example of the decisions faced on a hypothetical frost night is presented in the following section.

2.6.2 An Example of Decision Strategy During a Hypothetical Frost Night

- 10:15 a.m.: NWS forecast for 24-28°F in grower's area. Negligible wind velocity, typical radiational night, grower alerts foremen to possibility of frost. Foremen check condition of wind machines, amount of fuel, ordering more if necessary. High school students hearing forecast begin calling to offer services, but grower tells them to wait until 7:00 p.m. for decision.
- 4:15 p.m.: NWS forecast confirms 10:15 a.m. forecast.
- 6:00-7:00 p.m.: Grower makes first major decision on whether to just keep the foremen around for running the wind machines or hire the labor crew for the night to fire heaters. Grower decides to have full complement and tells students to arrive at 10:00 p.m.
- 10:15 p.m.: NWS forecast is lowered slightly to 23-27°F in most areas, possible 21°F in cold spots. Temperature at 32° in cold spots. Our grower is "risk adverse," that is, high quality tangerines for high grade fresh fruit, and consequently he orders the wind machines started in low-lying areas. He frets about the high cost of the diesel fuel, but is assured by the thought of a higher market price if frost causes damage statewide.
- 11:00 p.m.: Temperature at 32°F in most groves, 27°F in the "coldspots." Grower, on receiving telephone temperature reports from key groves, orders all wind machines started. Though 32°F will do no damage, he realizes that the wind machines have a greater efficiency in air mixture if started at 32°F or above. What bothers him is his uncertainty over the duration of the temperature. For example, even if it drops below 26°F for an hour, he will suffer no damage. He finishes the hour by receiving a report that a cloud bank is moving towards his area, which would raise his temperatures. He wonders if he has wasted fuel by starting the machines so early.
- 12:00 Midnight: Cloud bank hasn't materialized. Temperature falls to 26°F in cold spots, but there is still a rumor of cloud movement. Grower is uncertain over temperature duration. Being uncertain, he orders laborers to fire one-half of the heaters and turn off the wind machines in the cold spots. The remaining heaters are not used yet for two reasons: (1) if the temperature stays at 26°F or above only half would be needed anyway, (2) knowing that the heaters are good for only six hours of burning time, they are saved for the off-chance of an extended frost (usually the second night).
- 1:00 a.m.: Cold spot temperatures have been raised to 30°F by heaters, other groves at 32°F. So far so good.
- 2:00 a.m.: Cloud bank passes over briefly, temperatures rise and then rapidly fall. Grower was faced with uncertainty on whether to shut off heaters but decided to play it safe and leave heaters on.
- 3:00 a.m.: Temperatures falling rapidly in cold spots, at 24°F in some locations. Most groves holding at 30°F. Grower orders all heaters lit in colder groves. Since this is a radiational frost, he only has to protect until just after sunrise, and therefore he will have enough fuel for the remainder of the night.

However, if this were an advective freeze (i.e., the blowing cold front), relative grove elevation would make little difference, and protection would have to be extended even after sunrise. At 3:00 a.m. and 24°F in this situation, the grower would probably decide to sacrifice the fruit to save his trees. He would keep the heaters lit until grove temperature reached 26°F, turn them off, let the temperature fall to 24°F again and then relight, continuing this until the danger was over. Though these temperatures and durations would damage the fruit, the repeated breaks in duration 24-26°F would save his trees and furthermore save fuel, so that he could go until the late morning hours. A grower will always sacrifice the fruit to save the trees, since a damaged tree takes several years before it returns to normal production. It must be noted that the dormancy state of the tree plays a crucial role here. If the trees were in the "green flush" stage (i.e., not dormant), a temperature of even 27°F might have damaged them.

3:30 a.m.: Temperature up to 29°F in cold spots, 30°F in most groves.

3:30-7:00 a.m.: Air temperatures remain fairly constant, as do grove temperatures. Grower continues with wind machines in higher elevations, heaters in cold spots. Turns off wind machines and extinguishes heaters at 7:00 a.m.

8:00 a.m.: Laborers sent home. Orders forman to assess fruit damage.

The frost protection process, that is, the major decisions pertaining to the protection of fruit and trees, together with all information and major factors influencing their decisions, is illustrated in Figure 2.13, which shows as the input the NWS broadcasts and the readings of grove thermometers. Decisions are based on these inputs and other factors such as availability of frost protection technology (wind machines and/or heaters) and risk adverseness of growers, as was described in previous paragraphs. Due to the complexity of the whole program, only the decisions due to the major factors during the frost protection process are shown (Figure 2.13).

2.7 Measuring the Value of Improved Temperature Forecasting

During the 1976-77 frost season, Florida citrus growers received minimum temperature forecasts and frost/freeze warnings from the National Weather Service in the routine manner established over many years. That is to say, although SMS/GOES was already in orbit, the NWS agricultural forecasters did not

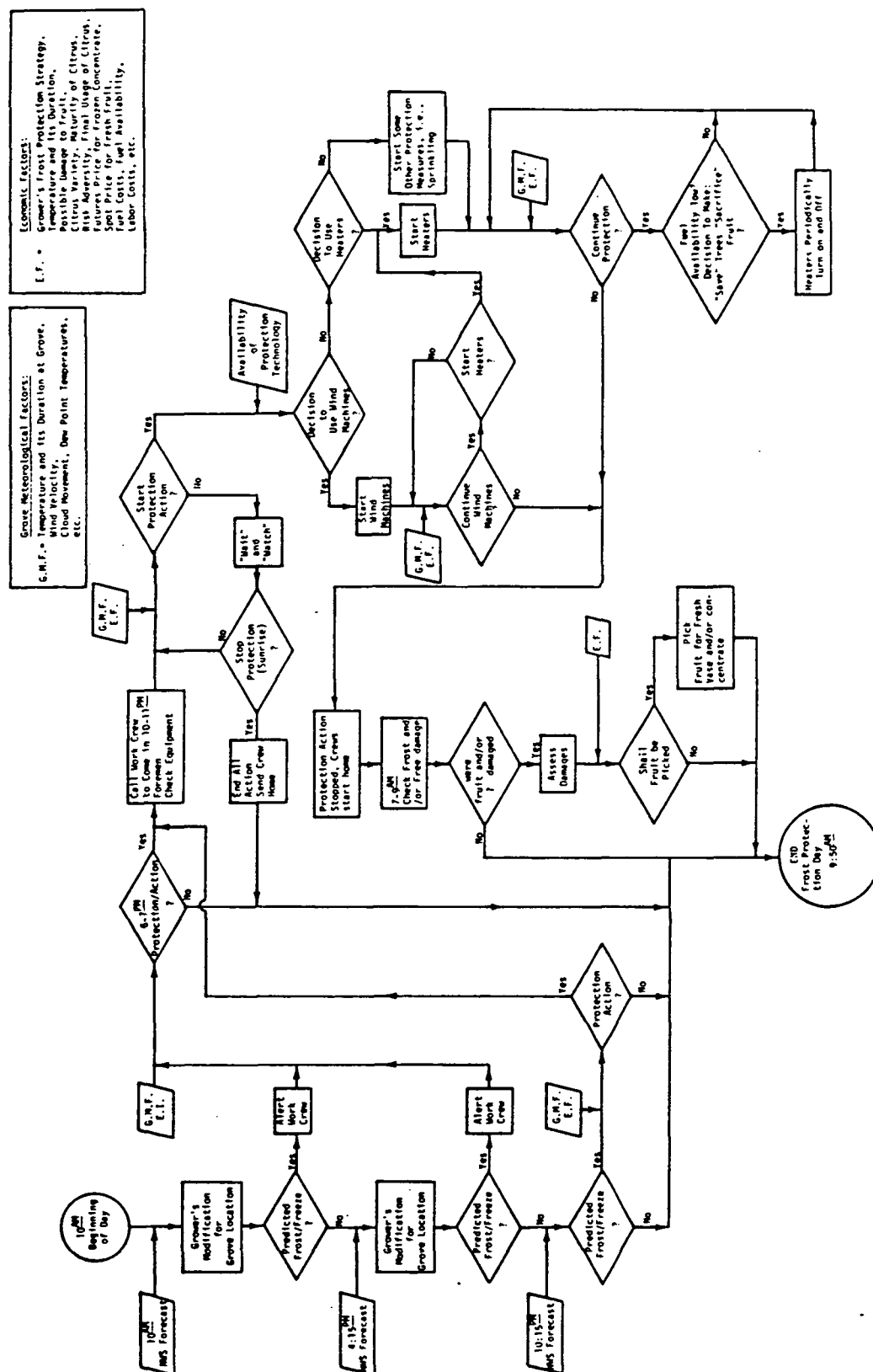


Figure 2.13 A Flowchart of a Typical Frost Protection Strategy During a Hypothetical Frost Event

make use of the satellite data^{*} in preparing their forecasts, nor did they use the University of Florida minimum temperature model. The data collection for the experiment commenced on December 1, 1976 as described in Section 3. Individual citrus growers in the experimental sample were asked to record details of their costs of protection and their losses associated with each frost or freeze that occurred from December 1, 1976 to March 31, 1977. The NWS provided a complete record of all agricultural temperature forecasts and readings of the NWS control thermometers scattered throughout the survey area. The latter are in the form of continuous thermographs.

During the 1977-78 frost season the National Weather Service at Ruskin was expected to have the equipment to receive on-line color images, and access to the University of Florida minimum temperature model by way of a minicomputer at Ruskin. It was anticipated that these new technological factors would improve the minimum temperature forecasts on clear cold nights (radiational freeze) in two ways: (1) the SMS/GOES spatial resolution of 4 n.mi. is considerably finer than the resolution available in previous months, (2) the frequency of updates of objective temperature data can be increased from two to three times a day to hourly.

The same experimental sample of citrus growers, minus dropouts, participated in the experiment again during the 1977-78 frost season. They provided basically the same cost and loss records (see Section 3 for details) as they provided during the 1976-77 frost season. The National Weather Service again provided a complete record of all agricultural temperature forecasts for the frost season and the NWS control thermometer readings for those thermometers in the survey area. This data was analyzed in the same way for both seasons in order to obtain a

^{*} There were, in fact, occasions when the NWS at Ruskin received black and white images from NASA/KSC during the 1976-77 season.

measure of the economic costs and losses associated with frost/freeze for each season. It was hoped that by subtracting the economic costs and losses for 1977-78 from those for 1976-77, a measure of the economic benefits of improved temperature forecasting could be derived. Figure 2.14 illustrates the basic concept of the economic evaluation.

Unfortunately, technical problems delayed installation, testing and use of both the color satellite picture electronics and the University of Florida forecasting model. As a result, the meteorologists at Ruskin did not incorporate the SMS/GOES data into their forecasting procedures in any systematic way during the 1977-78 season. The black and white pictures were available on most cold nights, and were used primarily as a means of checking the forecasts prepared by the usual method. It is expected that both the color satellite pictures and the forecasting model will be available to the Ruskin meteorologists throughout the 1978-79 frost

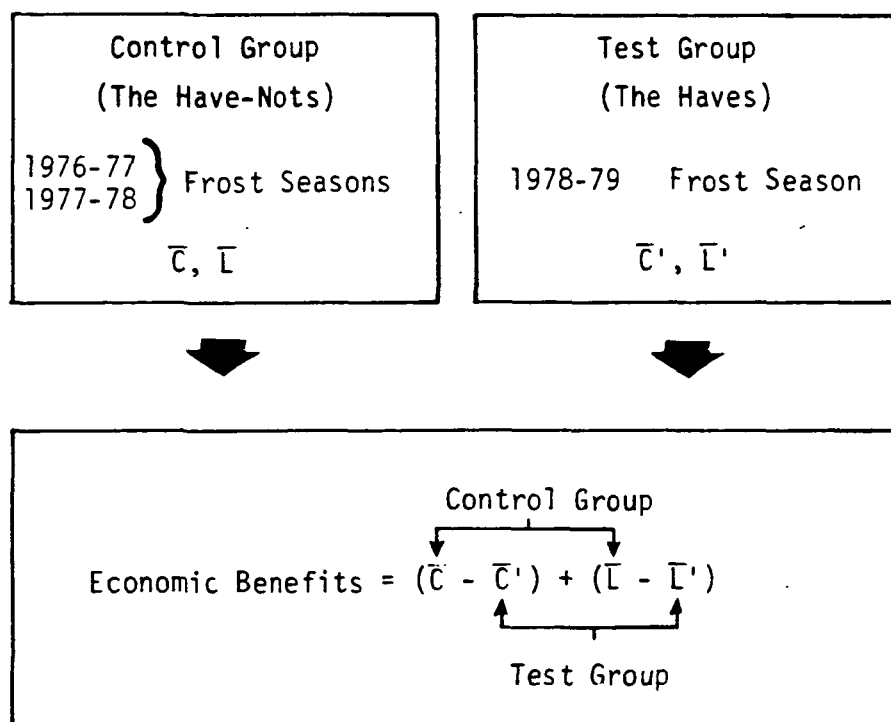


Figure 2.14 Basic Concept of Determination of Economic Benefits

season. It is hoped that the meteorologists will make extensive use of the improved forecasting data base provided to them so that 1978-79 may be used as the test group frost season in the planned benefits analysis. Data from the transitional 1977-78 season will be lumped, if this is found to be warranted, with the original control group data to provide additional control group observations. This may be possible since the use of the SMS/GOES data, in the absence of the University of Florida forecasting model, appears to have had no perceivable effect on the accuracy of the forecasts and citrus grower protect/no-protect decisions.

There are a number of difficulties with the methodology described above. The most obvious is the impact on the difference in costs and losses of the difference in weather itself, regardless of forecast accuracy. Another difficulty arises in relation to changes in cold protection strategies due to a combination of changing market factors, the changing price of fuel for orchard heaters and the evolving state-of-the-art with regard to the technology of protection.* The planned benefits analysis will attempt to deal with the effects of these factors, which are not explicitly a result of the design of the experiment.

The economic costs and losses in each season will be normalized to allow for the specific effects of that season's weather events. First, the observed costs and losses for each weather event in the sample groves will be related to the measure of weather severity developed in this study from grove and NWS temperature records. A statistical regression relationship will be estimated for the control and test groups, as illustrated in Figure 2.15. Results of the statistical analysis for 1976-77 and 1977-78 are reported in Section 5.7. Second, using the NOAA minimum temperature records for the years 1937-67, a typical pattern of weather events within a Florida

* Newer, more effective protection devices may also cost more.

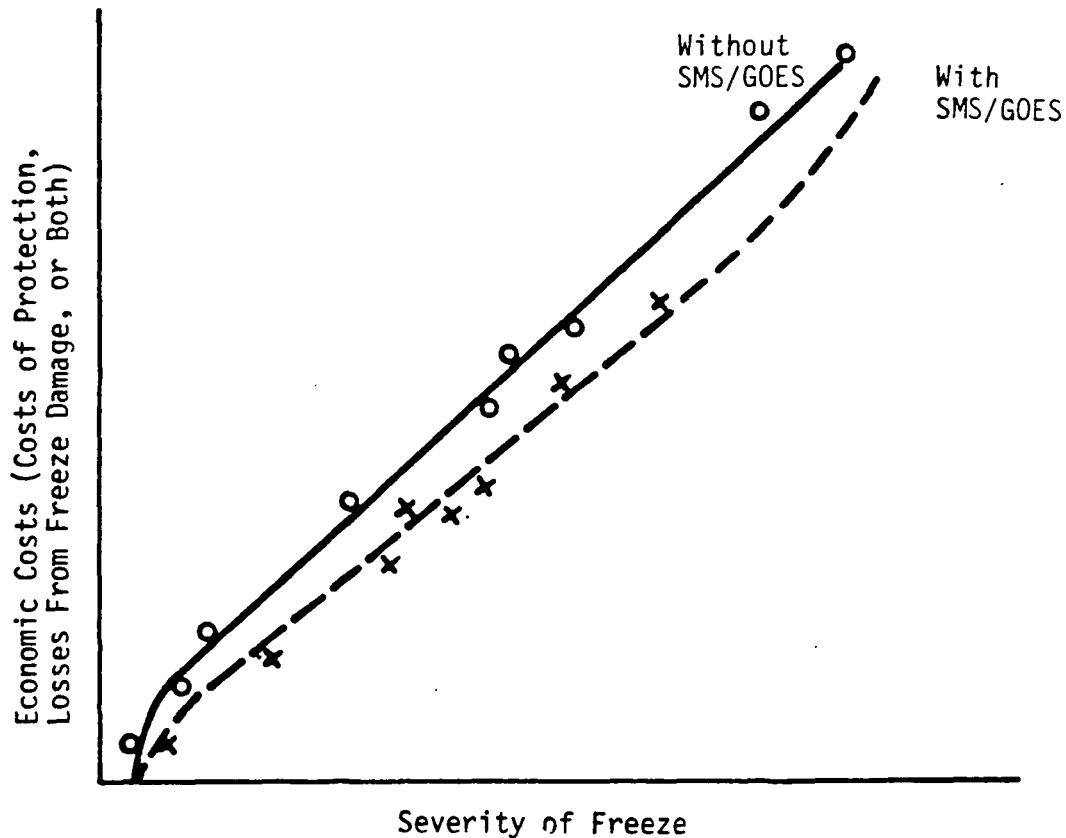


Figure 2.15 Hypothetical Relationship Between Weather Events and Economic Effects With and Without SMS/GOES

frost season will be developed. Finally, the experiment requires that the economic costs and losses for the control group be normalized to the typical pattern. The same procedure must be followed with the test group in 1979. As a result, the economic benefits of improved temperature forecasting will be normalized for the typical pattern of weather events.

The remaining difficulties will be handled by scaling the sample results to the total protected citrus production. The scaling factors will have to be adjusted to reflect changes in the cost per unit of cold protection between the 1976-77 and 1977-78 frost seasons and the 1978-79 season. While the details of this adjustment remain to be fully worked out, it is clear that minor fluctuations in the price

of factors in the application of cold protection should be ignored; only major trends and shifts should be included in the scaling. One trend which appears to be on-going is the reduction in protection activity in general due to the high price of fuel relative to the price of citrus fruit. This will not show up in the estimates of protected acreage, which are made based on capability rather than intention. Thus, it will be necessary to estimate this trend by another method such as purchases of fuel and/or sales of replacement equipment for protection.

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3. THE DESIGN OF THE EXPERIMENT

In order to demonstrate the economic benefits associated with improved meteorological information, it is necessary to measure a set of variables from which all costs and losses that accrue to the users of the information can be determined in terms of the quality of the information. To correctly compare the measured costs and losses which result from the utilization of improved information in the grower decision process, it is also necessary to measure other variables, such as grove temperature as a function of time (from which a measure of frost severity can be established), to establish the susceptibility of groves to freezing temperature damages, and to determine the specifics of frost forecasts. The following paragraphs describe the design of the experiment with specification of measurement procedures for all necessary variables.

3.1 Experiment Concept: Control and Test Groups

The Synchronous Meteorological Satellite (SMS/GOES) currently in orbit is furnishing temperature and other data to ground receiving stations. The National Weather Service is receiving much of this data at Ruskin, Florida and utilizing computer and display equipment which was installed at Ruskin beginning in November 1977, together with temperature forecast models developed at the University of Florida. Thus, actual temperature distributions of 4n.mi. spatial resolution and 0.5° centigrade temperature resolution can be observed hourly across the state of Florida and incorporated into the University of Florida forecast models. These forecasts can then be utilized, in conjunction with other data available to the National Weather Service, in the determination of the meteorological forecasts provided by the National Weather Service to the citrus growers.

It is anticipated that the citrus growers will, as they have in the past, utilize the temperature forecasts in their planning and decisions pertaining to frost protection. As has been discussed previously, SMS/GOES temperature data, in combination with the University of Florida forecast models, may result in improved temperature forecasts, which may in turn result in both reduced citrus crop protection costs and reduced citrus crop losses.

The economic portion of the experiment was designed to measure the economic benefits which result from improved frost forecasting as well as the benefits associated with reduced citrus crop protection costs and reduced crop losses due to frost/freezing damage. The experiment, because of the very limited number of frost seasons which can realistically be considered (i.e., the sampling problem), is not being planned to provide experimental verification data of the economic benefits from improved marketing decisions which may result from better knowledge of actual temperature distributions throughout the state of Florida.

It should be noted that the objective of the Florida ASVT is actually twofold, namely, (a) to demonstrate the impact of satellite-derived data in combination with computer forecasting models upon the accuracy and timeliness of frost forecasts to Florida citrus growers, and (b) to measure the resulting economic benefits. The experiment concepts to be discussed in the following pages are concerned primarily with the measurement of the economic and related (i.e., fuel conservation) benefits. Forecast accuracy is of concern only as it impacts the measurement of benefits; for example, forecast accuracy, as has already been mentioned, is a necessary input to the cost regression equation.

In order to measure the economic benefits of improved information (i.e., the SMS/GOES temperature data), it is necessary to establish and then compare the

costs and losses which would result with and without the improved information. This implies establishing two separate groups, namely, a test group (the "haves") and a control group (the "have-nots"). Since the National Weather Service does not at this time contemplate changing the information distribution network, and since current agricultural temperature forecasts are available to all citrus growers, it is not possible to establish control and test groups simultaneously in the state of Florida. This implies that the necessary isolation between the citrus growers comprising the control and test groups must be established through geographic and/or time displacement. Since geographic displacement within the state of Florida is not possible, it is theoretically possible to establish a control group outside of Florida. Serious doubt as to the credibility of a control group outside of Florida has been raised by representatives of the Florida citrus growers, the NWS, the USDA County Extension Agents and the University of Florida. Since it was deemed important to develop credible results, the idea of a control group outside the state of Florida was ruled out. Thus, it was necessary to establish the control group by time displacement.

It was therefore decided to establish a control group consisting of a number of growers during the 1976-77 frost season. The same growers who participated as the control group were expected to participate in the test group during the 1977-78 and other future frost seasons. The Florida citrus crop frost forecasting experiment plan is predicated upon this approach.

The basic concept of the experiment is as follows. During the 1976-77 frost season, the National Weather Service provided frost and temperature forecasts and measurements to the citrus growers in a business-as-usual fashion--that is, without the benefit of SMS/GOES temperature data, without the University of Florida forecasting models and without the computers and display equipment

required to operate on the SMS/GOES data with the University of Florida models. During the 1976-77 frost season, a selected set of citrus growers provided data on actual temperatures, decisions made and actions taken. These growers provided cost- and loss-related data. The National Weather Service provided data pertaining to temperature forecasts and actual observed temperatures. This data was analyzed by ECON, and the average cost and loss per event determined for the control group.

The same processes, as performed during the 1976-77 frost season, were repeated during the 1977-78 frost season. Data collection will continue until the end of 1978-79 season in order to establish a test group data base. It is assumed that the SMS/GOES data, together with the University of Florida forecasting models and improved computer and data display equipment, which have been available to the National Weather Service since the 1977-78 frost season, will continue to be used in the future. It was expected that the 1977-78 frost season would be a transitional one, since it was likely that during this season both growers and forecasters would be learning to adapt their decisions and actions to the improved information. The 1977-78 frost season was a transitional one in the sense that on a number of nights SMS/GOES data was available to the NWS on a computer color display. However, problems were encountered with the forecasting model so that it was not utilized, except in an experimental mode, during the 1977-78 frost season. As a result of an analysis of the data which was obtained during the 1977-78 frost season, it was decided to include the 1977-78 frost season data in the control group data base. The University of Florida temperature forecasting model will be available for use with the SMS/GOES data during the 1978-79 frost season. Thus, the data collected during the 1978-79 frost season will be considered as belonging to the test group.

The data provided by the test group will, as in the case of the control group, yield average cost and loss per event. As described in following pages, both the control group and the test group cost-and-loss-per-event data can be extrapolated to the annual cost and loss for the Florida citrus industry for an average frost season. The difference between control group and test group annual costs and losses extrapolated to an average frost season will provide an estimate of the average annual benefits which are a direct result of the improved information. These benefits will include the reduction of citrus grower frost protection costs and the reduction of crop losses, which are the result of the improved information. The benefit assessment will not include, because of the limited number of frost seasons (and hence data samples), those benefits which are the result of better marketing decisions made possible by the improved temperature distribution knowledge provided by the SMS/GOES data.

3.2 Methodology

3.2.1 Segmentation

The sample of Florida citrus groves falls into several major classes or segments. For each grove in the experiment sample, a citrus variety is identified^{*} at the beginning of the data collection. The varieties are:

- Early and midseason oranges
- Late (valencia) oranges
- Seeded grapefruit
- Seedless grapefruit
- Tangelos or temples
- Tangerines.

^{*} Occasionally more than one variety grows in a single grove, but this is rare.

Lemons and limes were excluded because they are not usually grown commercially in areas of the state which experience regular winter frosts, being too sensitive to cold weather.

The groves can also be segmented according to type of cold protection. There are major differences in cost and effectiveness of different methods of cold protection. For example, oil heaters cost more (per acre) to run than wind machines and are most effective in protecting the grove, particularly against an advective freeze. For calm, clear nights, the combination of heating and wind machines may be recommended, and so forth. In this experiment, the major types of cold protection are distinguished as follows:

- Heaters (return stack, jumbo, lazy flames)
- Wind machines (single and double)
- Overhead sprinklers (with or without microjet nozzles)
- Central systems for heating groves
- Irrigation
- Fog machines.

The differences in costs of protection and losses from freeze damage can be analyzed by type of protection because of the segmentation.

Citrus groves may differ in respect to the microclimate due to geographic location, elevation, the proximity of windbreaks and of large bodies of water. Predicting the effect of these factors on minimum temperatures in the grove on cold nights is very difficult. Nevertheless, observations on the spatial distribution of temperature for a night for frost or freeze permit segmentation of the experimental citrus groves according to severity of frost/freezing. An index of severity of is developed in Section 3.6. For each weather event, the groves can be segmented by the level of severity. Costs of protection and losses from frost/freezing damage can be analyzed according to the degree of severity observed.

3.2.2 The Sampling Plan

The distribution of the protected acreage throughout the citrus region is very important in determining the target population, the survey population, and finally, the sampling frame. The target population is considered to be the total citrus-producing acreage which is protected against the freezing temperatures. However, the protection of citrus is less important in the southern areas of peninsular Florida, and only acreage allocated for the specific fruit and nurseries is protected. Also, the citrus-bearing acreage in the northern areas of the peninsula, even if it is almost all protected, represents only a small fraction of the total protected acreage. Therefore, it seems reasonable to exclude the citrus-bearing protected acreage in the southern and northern areas of the peninsula from the data-gathering portion of the experiment. The survey population is therefore defined as the citrus-bearing acreage which is protected against the possibility of freezing temperatures, and is geographically located in the central region of the peninsula of Florida. It is this population from which cooperative growers were selected for participation in the control and test groups. The survey population is estimated as comprising approximately 95 percent of the target population.

In order to estimate both the number of growers included in the target population and the number growers who might participate in the economic experiment, ECON contacted two USDA multicounty extension agents in 1976. These extension agents^{*} assist citrus growers in the prime protected producing areas of Polk, Lake, Orange and other east coast counties. Table 3.1 shows their estimates of total acreage, number of growers and number of groves in their jurisdiction. The protected acres within this region represent more than 75 percent of the total protected acreage in Florida.

^{*} John Jackson and Tom Oswalt.

Table 3.1 Estimate of Grower Survey Population* and Sample Size Based on Data from the Major Frost-Affected Citrus-Producing Areas**

	Total Acreage	Growers	Groves***
Total	326,000	7,200	8,000-9,000
Frost Protected	51,000	230	1,200-1,300
Frost Protected and Probable Participants	20,000	55	400-600
* At start of experiment (1976-77 frost season). ** Based on Lake, Orange and Polk Counties and part of other counties on east coast; estimation done in April 1976. *** Assumes average grove size of 40 acres.			

The survey population may be divided for sampling purposes into sampling units. For the case at hand, the sampling unit is the citrus-producing grove which is protected against the effects of frost and/or freeze. A grove containing a minimum of 50 citrus-bearing trees is considered to be the smallest unit. This is consistent with the Florida Department of Agriculture's Commercial Citrus Inventory published biennially.* Groves vary in size; the large groves may contain several thousand acres of trees and the effect of the size should be included in an evaluation of the sampling.

There are two basic types of sampling frames, namely, the area frame sampling and the list frame sampling. These sampling frames, and their combination, the multiframe sampling, are currently used in the collection of data for agricultural statistics.

* Commercial Citrus Inventory, Florida Department of Agriculture, Florida Crop and Livestock Reporting Service, Orlando, Florida.

In area frame sampling, the frame consists of an aggregation of characteristics concerned with agriculture associated with these sample segments using three different concepts: The closed segment includes all agriculture that is inside the segment boundaries and excludes all that is not. In the open segment all activities of farms with headquarters located inside the segment are associated with the segment even if some activities are outside the segment boundaries. In the weighted segment, all agriculture associated with a farm is attributed to the segment in proportion to the fraction of the farm acreage that is inside the segment.

A list frame is a list of identified elements from the sampled population. For the particular case under consideration, lists of names and addresses of growers and grove managers will be used in collection of information. The cost of data collection from the list frame is relatively low. The indexing of various characteristics used for efficient stratified sample designs can be easily developed and incorporated in the list frame. The list frame, however, is almost never "complete" because the units of the frame (i.e., groves), are continually changing. Therefore, only nonprobability sampling is used with a list frame.

This disadvantage is removed in multiple-frame sampling where more than one frame is used. For agricultural statistical purposes this implies the use of both a list frame and an area frame. This method is very effective for specialized types of crops, such as citrus, which are not correlated with land alone. For the citrus experiment, some of the main characteristics pertinent to the sampling, such as frost protection technology, variety of citrus, use of crop, micrometeorological factors and the cost associated with the frost/freeze protection, are not associated with land. Therefore, most of the data for population can be collected more

efficiently through the list frame. The area frame complements the list frame and thus allows the application of probability surveys.

A variety of list sources was available for the development of the list frame to be used in the experiment. The following organizations maintain statistical records which were available for use:

- Florida Department of Agriculture and Consumer Services
- Florida Crop and Livestock Reporting Service
- Agricultural Stabilization and Conservation Service
- State Farm Census
- Assessor's records
- State government records maintained for inspection and controls
- Records of Florida Cooperative Extension Service, University of Florida, Institute of Food and Agricultural Science
- Citrus grower's records.

One of the most important sources for the construction of the list frame was the Florida Cooperative Extension Service, whose records are periodically updated by the county extension agents. They have an intimate knowledge of almost all citrus groves in their districts (one or more counties) and maintain a constant communication with citrus growers. Their help was especially valuable in determining the location and distribution of protected groves, the availability of cooperative growers who were willing to supply information on their costs of protection and losses from freeze damage, and the relationship of these groves to the target population.

In designing the sampling plan for the economics portion of the experiment, the overriding concern was the availability of cooperative citrus growers with protected acreage in central Florida. The flow of timely and accurate information

from these growers was essential to the success of the experiment. Random sampling thus was excluded as a possibility since the response rate from randomly selected citrus growers was judged too low by University of Florida fruit scientists and ten county extension agents. It was decided to use a nonprobability sample based on the list frame existing in the county extension service records. For this purpose a guideline was prepared indicating the number and type of groves desired in each county (of the eight-county area in central Florida) and the county extension agents were asked to submit lists of growers and groves which would be used for the experiment. ECON interviewed a number of growers who agreed to participate, but most of the selection process was in the hands of the extension agents. The resulting sample (Table 3.2) included the majority of growers who (a) have protection capability, (b) are willing to divulge their cost and loss information.

By the end of the second year of data collection, a number of groves had dropped out of the sample. Total attrition amounted to 46 groves, with 199 remaining in the sample, as shown in the table.*

3.2.3 Expansion From Sample to Industry

The results in terms of the costs and losses experienced by the citrus growers for the sample groves, within a frost season, represent the basic economic data for the experimental sample. From these results, it is possible to infer the economic impact of the frosts and freezes on the part of the citrus industry which employs cold protection, by "expanding" all the sample results. The factors of expansion are derived as follows. Let C_{IJK} , L_{IJK} and A_{IJK} be costs per acre, losses per acre and acreage for county I, fruit type J within sample unit (grove) K. Most groves are homogeneous as to fruit type, and of course lie within one county. Also, let

* The remaining growers have indicated a willingness to continue participating in the experiment during the 1978-79 season.

Table 3.2 Sample Groves by County		
County	Number of Sample Groves 1976-77	Number of Sample Groves 1977-78
Polk	109	93
Lake	51	44
Orange	38	30
Hillsborough	15	7
Marion	14	14
Highlands	10	3
Hardee	4	4
Osceola	4	4

CP_I = total protected acreage in county I

CT_{IJ} = total acreage of fruit type J in county I

CT_I = total acreage in county I = $\sum_J CT_{IJ}$

First, the total protected acreage in county I of fruit type J is estimated as follows:

$$\hat{A}_{IJ} = CT_{IJ} * CP_I / CT_I$$

Then the protection costs per acre and freeze losses per acre can be estimated for each county and fruit type as follows:

$$\hat{C}_{IJ} = \sum_k A_{IJK} * C_{IJK} / \sum_k A_{IJK}$$

$$\hat{L}_{IJ} = \sum_k A_{IJK} * L_{IJK} / \sum_k A_{IJK}$$

Finally, the expansion is completed by calculating the total protection cost and freeze loss (for protected acreage):

$$\hat{C} = \sum_I \sum_J \hat{C}_{IJ} * \hat{A}_{IJ}$$

$$\hat{L} = \sum_I \sum_J \hat{L}_{IJ} * \hat{A}_{IJ}$$

In actual practice, the exogenous industry statistics on protected acreage by county and fruit type are difficult to obtain, and some approximations are necessary. These are described in Section 5.6 of this report.

3.2.4 Normalization of Costs and Losses to Standard Weather Pattern

The results for the 1976-77 and 1977-78 seasons may differ from each other and from the results for the 1978-79 season due to differences in the weather itself. This is not the same as the economic effect of improved temperature forecasting. Clearly, it is essential to base the comparison of economic costs and losses between the control group and the test group on a standard weather pattern; in other words, to normalize the results for weather differences.

The National Weather Service in Florida has provided ECON with a computer tape which contains temperature profiles of the years 1937 to 1967 for all nights from November 1 to April 1 on which the observed temperature fell below 32°F. These profiles were recorded at 72 NWS thermometers in the citrus-growing region of Florida. Analysis of this weather data allows calculation of the standard weather pattern.* For both the control group (1976-77 and 1977-78) and the test group (1978-79), statistical relationships between costs and weather severity and losses and weather severity will be estimated. The equations that describe these relationships can be written formally as:

*Details of the procedures are provided in "Economic Consequences of Improved Temperature Forecasts: An Experiment With the Florida Citrus Growers (Control Group Results)," Appendix D, ECON Report No. 77-261-1, dated November 30, 1977.

$$\ln(\text{LABOR}+1) = \beta_0 + \beta_1 (\ln(\text{DUR28}+1)) + \beta_2 \text{MINFOR} + \epsilon$$

$$\ln(\text{NONLAB}+1) = \beta_0 + \beta_1 (\ln(\text{LABOR}+1)) + \beta_2 (\ln(\text{DUR28}+1)) + \beta_3 \text{MINFOR} + \epsilon$$

$$\text{LOSSPA} = \beta_0 + \beta_1 \text{NONLAB} + \beta_2 \text{FSEV} + \epsilon$$

where

LABOR = per acre labor costs

NONLAB = per acre nonlabor costs

DUR28 = duration of temperature below 28°F

MINFOR = minimum of forecast range

LOSSPA = per acre dollar loss

FSEV = frost severity index

$\beta_0, \beta_1, \dots, \beta_n$ = estimated regression coefficients

ϵ = random disturbance or error (assumed normal with 0 mean).

The regression coefficients (β 's) are estimated separately for each type of fruit, location (northern or southern citrus producing counties) and frost season. Once the coefficients of these equations have been estimated by regression, the standard weather pattern obtained from the 30-year temperature profiles and the distributions of forecast error developed in the two-year forecast verification can be used to generate normalized costs, $\bar{C}$, and losses, $\bar{L}$. This can be accomplished by computing hypothetical costs and losses for each grove and each cold night in the 30-year data, effectively simulating the 30 years of frost in the sample groves. To compute nightly costs for each grove, both durations below 28° and the minimum forecast temperature will be needed. The former can be obtained, with minor computations, directly from the historical weather tape. To determine the minimum forecast temperature, it will be necessary to use an additional simulation

to select a value from an appropriate distribution of forecast errors. This number can then be added to the actual minimum temperature given on the tape to yield a simulated forecast for the particular grove and night. To compute losses for each grove and night, only a measure of frost severity will be needed since nonlabor cost, the other determinant of losses, is estimated in the earlier regression. Frost severity is calculated directly from the data on the 30-year tape, using the procedure outlined in Section 3.6.1 below. When the simulation of costs and losses over 30 years is complete, an average cost and loss can be computed for each grove and each calendar date.

3.3 The Sample of Citrus Growers

The major citrus-producing area in Florida is located in the central region of the state, around the sandy ridge extending north-south within the interior of the peninsula. The results of the biennial survey by the Florida Crop and Livestock Reporting Service (Figures 2.2 and 2.3) show that, of Florida's 706,200 total citrus-bearing acreage, almost 51 percent (406,000 acres) is located in Marion, Lake, Orange, Polk, Hillsborough, Osceola, Hardee and Highlands counties, which are all located in the central part of the state. The Indian River producing region along the east coast has more favorable climatic conditions and generally does not require citrus protection.

A survey by the Florida Citrus Mutual in 1974 estimated that a total of 105,745 acres utilize heaters for frost protection (Table 3.3) and that 78,019 of these acres (73.8 percent) are in the above listed counties. No survey was performed to estimate the acreage protected by wind machines and other frost/freeze protection methods, but it is reasonable to assume that the protected citrus

Table 3.3 Estimated Citrus Acreage Protected by Heaters

County	Total Acres	Estimated Heated Acres
Polk	150,122	30,000
Volusia	12,324	7,300
Brevard	20,160	2,000
Hendry	22,447	--
Dade	4,531	680
Seminole	12,067	200
Manatee	18,943	4,546
Hardee	50,716	3,042
Lake - Orange	208,757	8,350
Hillsborough	59,727	23,293
Marion	13,988	7,134
Osceola	19,051	4,500
Highlands	38,803	6,200
Pasco	42,331	4,000
TOTAL	673,967	101,245
Broward	5,030	--
Indian River	51,815	--
Martin	41,385	--
Palm Beach	17,566	--
St. Lucie	75,397	--
Charlotte	6,734	--
Collier	5,052	--
Desoto	25,478	500
Glades	1,572	--
Lee	7,439	--
Okeechobee	3,597	--
Pinellas	5,825	250
Sarasota	1,612	50
TOTAL	248,502	800
Putnam	4,709	1,400
Sumter	2,379	500
Citrus	2,222	500
Hernando	9,150	1,300
TOTAL	18,460	3,700
GRAND TOTALS	940,929	105,745
SOURCE: Florida Citrus Mutual, 1974.		

acreage in the seven counties of the central part of the state represents more than 75 percent^{*} of all Florida's acreage protected against frost and/or freeze.

The distribution of the protected acreage throughout the citrus region was very important in determining the target population, the survey population, and finally, the sampling frame. The target population was considered to be the total citrus-producing acreage that is protected against the possibility of freezing temperatures. However, the protection of citrus is less important in southern areas of peninsular Florida and only acreage allocated for special fruit (limes, lemons, etc.) and nurseries is protected. Also, the citrus-bearing acreage in the northern areas of the peninsula, even if almost all protected, represents only a small fraction of the total protected acreage. Therefore, it was reasonable to exclude the citrus-bearing protected acreage in the southern and northern areas of the peninsula from the data-gathering portion of the experiment, and to define the survey population as the citrus-bearing acreage which is protected against the possibility of freezing temperatures and is geographically located in the central region of the Florida peninsula. Figure 3.1 shows the survey population and its relation to the total citrus acreage. It was this population from which growers were selected for participation in the control and test groups. The survey population is estimated as comprising approximately 95 percent of the target population.

Several methods are used for the collection of data for agricultural statistics.^{**} The method which is most effective for the data collection associated

^{*} This percentage would be higher for the protection technology which is more capital intensive (such as wind machines).

^{**} Scope and Methods of the Statistical Reporting Service, U.S. Department of Agriculture, Miscellaneous Publication No. 1308, Washington, DC, 1975.

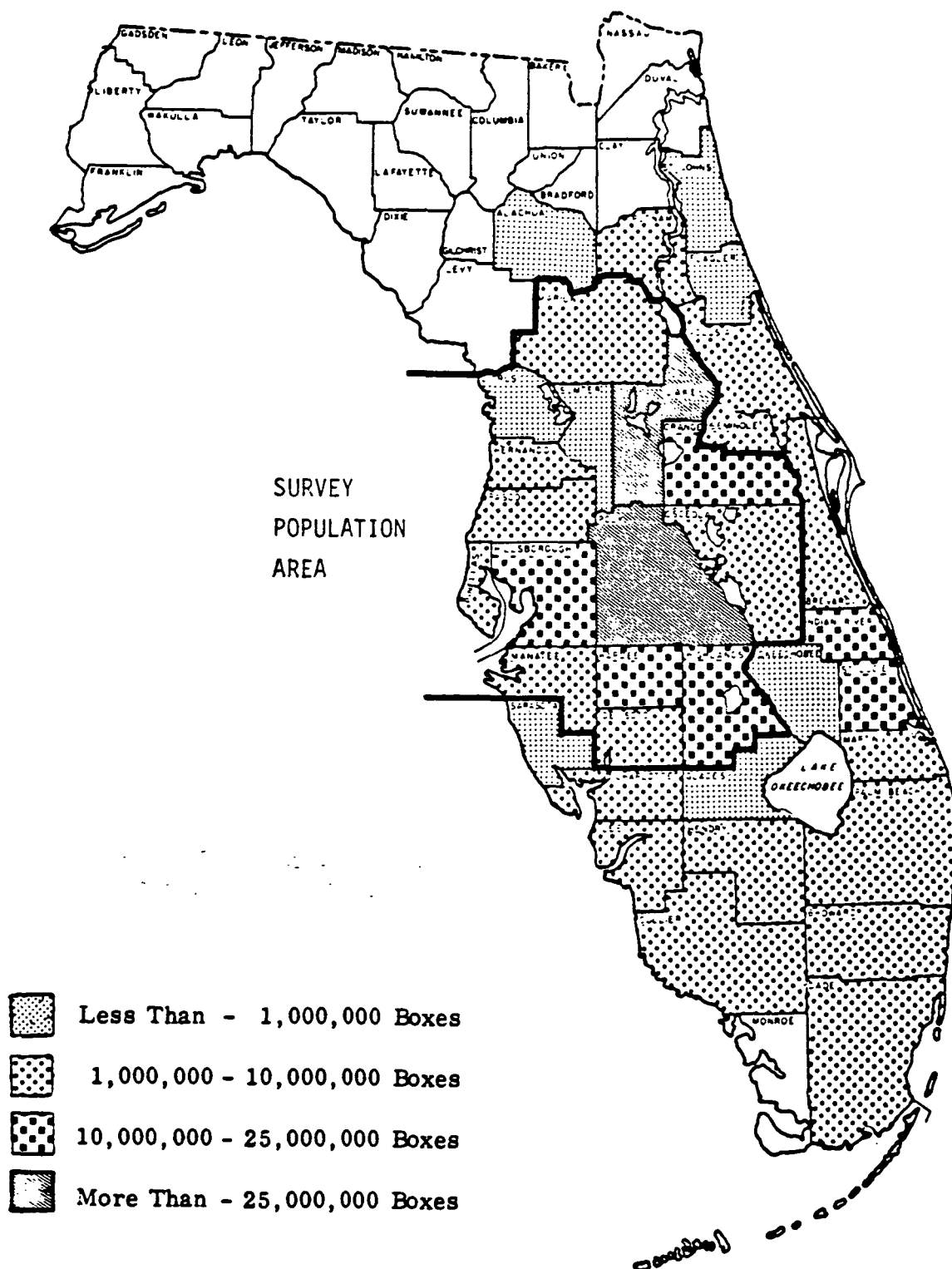


Figure 3.1 Relation of Survey Population (Protected Citrus Acreage) to Total Citrus Acreage in Terms of Citrus Production (1974-75)

with specialized types of crops such as citrus, which are not correlated with land alone, is "list frame sampling." Once the list frame is established, the specific elements can be selected for inclusion as part of the control and/or test groups taking into account their specific characteristics.

The development of the list frame (list of all participants) used in the experiment was primarily based upon the records of the Florida Cooperative Extension Service, which are periodically updated by the county extension agents. The agents have an intimate knowledge of almost all citrus groves in their districts (one or more counties) and maintain a constant communication with citrus growers. Their help was instrumental in the construction of a list and selection of all growers (and groves) who participated in the experiment. A key element in the selection of growers for participation in the experiment was the county extension agent assessment of the probable grower cooperativeness in providing data and filling out forms over extended periods of time. The cooperation of growers, grove managers and caretakers is most important in the effort to obtain as complete a list of all measured characteristics as possible. The complete and timely return of questionnaires and cooperation during interviews is necessary for the successful collection of data.

3.4 Grower Data Collection

Grower data collection is concerned with obtaining information about the sample grove characteristics, their past history and present and future status, and frost protection decisions, actions, costs and losses. The most effective way of obtaining this information is to obtain it directly from the people who in the past and the present take care of the groves which are part of the experiment. They are called "growers" even if they do not own the groves and are only the managers or caretakers of the groves.

In general, data can be collected by interviewing the experiment participants or by obtaining written responses of participants to prearranged questions in a questionnaire. Although both interviews and questionnaires rely heavily upon the validity of verbal reports, there are important differences between these two methods.

In an interview, because the interviewer and the person interviewed are in direct contact when the questions are asked and answered, there is great flexibility in eliciting information. The interview surveys typically attain higher response rates than surveys using the written answers of the respondents (participating growers in our case). The presence of an interviewer generally decreases the number of "don't know" and "no" answers. Interviewers also clarify questions which may be confusing to the respondent and thereby obtain relevant responses. Finally, the interviewer can observe as well as ask questions and his observations sometimes provide answers to the questions which would have remained unanswered on a questionnaire. However, the cost associated with the interview survey is often prohibitive.

The questionnaire survey is a much less expensive procedure. The questionnaires are usually mailed or handed to respondents with a minimum of explanation and the answered forms are then returned by mail. They can be administered to a large number of individuals simultaneously, while an interview survey calls for questioning each individual separately. With a given amount of funds it is then possible to obtain a much larger sample with a questionnaire survey than by personally interviewing each respondent.

A data form questionnaire has an impersonal character since the wording and the order of questions, the instructions about the meaning of questions and how to fill out the forms in general, are all standardized. This standardization ensures

some degree of uniformity and helps in the subsequent evaluation of responses. On the other hand, a question with standard wording may have different meanings for different people or might be incomprehensible to some respondents. Carefully written instructions and assistance to the subjects during the administration of the questionnaire help to solve this problem.

Another advantage of questionnaires is their anonymity. The respondents may feel freer to express views they fear might be disapproved of otherwise or get them into trouble. Finally, it is characteristic of the questionnaires that they place less pressure on the subject for immediate response. Having been given an ample time to answer the questions in a written form, a respondent can consider them more carefully. However, this advantage brings along a disadvantage in delayed response from some subjects and also demands a personal effort on the part of the subjects to return the answered questionnaires.

The questionnaire technique was extensively employed during the data collection for this experiment. It was, however, supplemented by interviews in order to clarify some questions, increase the rate of response in general, and increase the reliability of results.

The citrus growers who participated in the control group but did not respond by mailing their completed forms were contacted by the county extension agents who administered their regions. The agents interviewed the growers either in person or via telephone. Additional interviewing of some growers was also done by ECON employees, especially in the districts where a large number of participating growers represented an excessive work load for the agents. It is not possible to measure exactly the increase in responses due to this additional effort of interviewing the growers, but it could be said with certainty that the combination of both survey techniques, mailed questionnaires and personal interviewing, has contributed greatly to the overall high rate of response.

3.4.1 Design of Questionnaires

In general, questionnaires are designed to obtain information by asking questions about what a respondent knows, believes or expects, feels or wants, intends or does or has done, and about his explanation or reasons for any of the preceding. The questions are not in an arbitrary order. The order of questions, the number of questions about the same subject, and their grouping in "batteries" is very carefully planned. The order to questions is important so that they do not affect each other nor offend or make the respondents adopt a defensive attitude towards the inquiry.* The questions which might affect the answers to other questions are dispersed in the questionnaire. The most general questions are normally asked first and the more specialized ones are asked at the end of a group of questions about the same subject.** The first questions are easy ones, sometimes only of little relevance to the investigation, and also have as a purpose "relaxing" the respondent and gaining his confidence. When certain delicate questions must be asked, they are generally put at the end of the questionnaire or at the end of a "battery" of questions on any particular subject; by this time the respondent is in a trusting frame of mind and there is more chance of obtaining a reply. Even if the respondent takes offense, answers to the preceding questions will not be distorted.

The total number of questions must not be too great, to avoid tiring the respondent, resulting in the last questions being answered less accurately. Questions on a variety of subjects are usually grouped together. The questions on the same subject help to limit the errors and the answers can be compared and checked; the analysis is thus given an additional depth.

* Duverger, M., An Introduction to the Social Sciences, F. A. Praeger, New York, 1964.

** This arrangement of questions is called "the funnel technique."

The questionnaire survey measures a variety of variables. These variables are then categorized using several measurement techniques referred to as "nominal," "ordinal," "interval" and "ratio" scales.* The nominal scale merely distinguishes the categories that comprise a given variable. For example,** region of the county, grove location and type of protective technology are nominal variables. The categories comprising a nominal variable are mutually exclusive, but they bear no other relationship to one another.

The ordinal scale reflects a rank-order among the categories comprising a variable. The question: "On a scale of one to ten, how much confidence do you have in the NWS forecast?" (question four in the Nightly Frost/Freeze Protection Activity Report) would be an example of a measurement on an ordinal scale.

The interval scale also utilizes numbers to describe conditions. The numbers have, however, definite meanings such as measurements of temperatures on the Fahrenheit scale. The ratio scale is similar to the interval scale and has the additional characteristic of true zero. For example, the age of citrus trees is measured on the ratio scale.

The form of questions has a great influence on the response to them. The text of questions should be as simple as possible, the language used should be familiar and easily comprehensible to all respondents. The questionnaire items should be clear and unambiguous. A lack of understanding between the researchers and respondents could arise either when the respondents have given little or no attention to the topic of an investigation and the researchers who formulate questions are deeply involved in it, or the researchers have only a superficial

* Babbie, E. R., Survey Research Methods, Wadsworth Publishing Co., Inc., Belmont, California, 1973.

** Variables from the questionnaires designed in the experiment are used as examples.

understanding of the topic and fail to specify the intent of their questions sufficiently. During this experiment this problem was minimized by pretesting the questionnaires whenever possible, and by frequent consultations with the experts in the citrus industry.

The questionnaires contain two basic forms of questions: open-end and closed-end questions. In the case of open-end questions, the respondent is asked to provide his own answer to the question and is provided with a space to write his answer. This type of question represents a problem during processing of answers because of the need for additional coding and also because there is a danger that the answers might be essentially irrelevant to the topic of the investigation.

In the case of closed-end questions, the respondent is asked to select his answer from among a provided list. The closed-end questions provide a greater uniformity of responses and are more easily processed. The response categories provided should be exhaustive and they should include all possible responses that might be expected. Also, the answer categories should be mutually exclusive--the respondent should not feel compelled to select more than one. Multiple answers, which are sometimes desirable, create difficulties in processing, which can be overcome by careful coding of the results.

During the experiment with the Florida citrus growers, a thorough study of the theoretical considerations and general guidelines of questionnaire design was made. In order to gather all necessary information for the evaluation of economic benefits due to the improved temperature forecasts, three different types of questionnaires or reports were designed and utilized: (a) Grove Background Report, (b) Nightly Frost/Freeze Protection Activity Report, and (c) Damage Report. All three reports have a different character and were designed to provide a specific type of information. In order to enable the growers to easily distinguish the three

different types of reports, they were printed on colored paper. Green paper was used for Grove Background Reports (these forms were then called "green forms"), white paper was used for the Nightly Frost/Freeze Protection Activity Reports ("white forms") and, finally, pink paper was used for the Damage Reports ("pink forms"). These are illustrated in Figures 3.2 to 3.8. Instructions on how to complete the questionnaires were given separately for each type of questionnaire and were printed on paper of a corresponding color (i.e., "green forms" instructions on green paper, etc.). This distinction of forms by their color proved to be very convenient during the administration of the questionnaire survey.

The following sections briefly describe the three different reports which were used during the data collection for the experiment with Florida citrus growers.

3.4.2 Grove Background Report^{*} (Refer to Figure 3.2)

The Grove Background Report is designed to gather general information concerning the groves selected for the experiment. The information provided by this report is assumed to be invariant during the Florida winter season (from December to March). This report is completed prior to the start of the frost season.

The format of the report is such that a short introductory statement at the top informs the respondent that the questions are to be answered only once at the beginning of the frost/freezing protection season. A box is provided in the right hand corner of the green form for an identification number which is uniquely assigned to every grove in the sample. The number has two parts: the first part identifies the county in which the grove is located and corresponds to a part of the automobile

^{*} Examples of filled out reports and the corresponding instructions (as given to the citrus growers) are presented in Appendix B.

license tag numbers of that county; the second part is the serial number in the list of all groves which are administered by that county extension agent.

The questions in the Grove Background Report are arranged into five content subsections, each labeled by an underlined heading. The first subsection groups together twelve questions concerning the description and characteristics of the grove. To avoid confusion, the definition of a "grove" is given in the instructions for this report (a need for this definition was discovered during a pretesting of the questionnaire). A "grove" is defined as a land area (a) with citrus of the same variety, (b) planted mostly at the same time, (c) having a uniform degree of frost/freeze protection and (d) subject to the same management and agricultural practices.

Each grove usually has its own name or number which is used by the grower. This name is filled out as the response to the first question and is used as a cross-reference during the evaluation of collected data. The second question is concerned with the grove's geographical location. The State of Florida is divided into townships, ranges and sections and these three parameters help to identify the location of a grove. This information is necessary to obtain the FCIC classification for the grove, which is needed for scaling purposes. The following two questions are of a closed-end type and a grower is asked to select the variety of citrus grown in the grove and the type of rootstock from the lists provided.

Citrus trees reach their full productivity when they are about seven years old. Therefore, the fifth and sixth questions are concerned with the age of trees as well as percentage of all trees which are resets (new trees replanted in place of older trees which have died) less than seven years of age and thus not in full production. Question seven is concerned with the citrus-bearing area, excluding such things as empty spaces, roads and nonproducing trees. Questions eight

This section records some specific information about one of the groves selected for this study. Most of this information will not change from December to March. Please be as specific as possible in answering these questions.

DESCRIPTION AND CHARACTERISTICS OF THE GROVE

1. Your own grove identification: _____
2. Grove location: _____ / _____ / _____
Section Township Range
3. Variety of Citrus grown in this grove: _____

CIRCLE ONE NUMBER

- 1 Early Oranges
2 Midseason Oranges
3 Late (Valencia) Oranges
4 Temples
5 Tangelos
6 Tangerines & Honey Tangerines
7 Seedy Grapefruit
8 White Seedless Grapefruit
9 Red-Pink Seedless Grapefruit
10 Some other variety; PLEASE SPECIFY: _____

4. Type of rootstock: 1 Rough Lemon 4 Trifoliolate Orange
2 Sour Orange 5 Carrizo Citrange
3 Cleopatra Mandarin 6 Other
CIRCLE ONE NUMBER

5. Year grove was planted: _____
6. Percentage of all trees that are resets less than 7 years of age or skips: _____ percent

7. Grove area (If possible be as specific as tenths of an acre of actual citrus bearing tree acres.): _____ acres

8. Grove terrain: 1 High Ground
2 Low Ground
3 Other; PLEASE DESCRIBE _____
CIRCLE ONE NUMBER

9. Grove soil type: 1 Ridge
2 Flatwoods
3 Other; PLEASE DESCRIBE _____
CIRCLE ONE NUMBER

10. Are there any large bodies of water which may influence your grove? 1 Yes
2 No

11. Is there a control thermometer associated with this grove which is outside of the protected area? 1 Yes
2 No

12. If you know the Federal Crop Insurance Corporation classification of this grove would you please write it down? _____

If you have any questions, call your county extension agent.

GROVE STATUS

13. Month of expected harvest: 1 January 7 July
2 February 8 August
3 March 9 September
4 April 10 October
5 May 11 November
6 June 12 December

CIRCLE ONE NUMBER

14. Average yield in this grove in the

- 1973-74 season: _____ boxes per grove
1974-75 season: _____ boxes per grove
1975-76 season: _____ boxes per grove

15. Estimate of yield for the 1976-77 season: _____ boxes per grove

16. Grove has experienced frost/freeze damage in the past three years which has reduced the grove's productivity or damaged the trees:

- 1 Yes 2 No
When did this damage occur? Month: _____ Year: _____
Month: _____ Year: _____
Month: _____ Year: _____

17. Did this damage prompt any additional frost/freeze protection measures for this grove? 1 Yes
2 No

MARKETING PLANS

18. At this time, do you intend to produce the citrus from this grove for fresh or processed market? 1 Fresh
2 Processed
3 Don't know
CIRCLE ONE NUMBER

19. What are the primary reasons you plan to market this fruit in this manner? 1 Variety or quality of fruit
2 Expected market price
3 Anticipated costs of freeze/frost protection
4 Other; PLEASE EXPLAIN: _____
CIRCLE AS MANY AS APPLY

FROST/FREEZE PROTECTION MEASURES

20. Wind machines used in this grove? 1 Yes
2 No...GO TO QUESTION 22

21. Wind machine data for this grove:

Type of Machines	Number of Machines	Type of Fuel	Average Fuel Consumption Rate*

*diesel.....gallons/hour
gasoline.....gallons/hour
electricity...kilowatts/hour
propane.....pounds/hour

22. Heaters used in this grove? 1 Yes
2 No...GO TO QUESTION 26

23. Heater data for this grove:

Type of Heaters	Number of Heaters	Type of Fuel	Average Fuel Consumption Rate*

*diesel fuel...gallons/hour
propane.....pounds/hour

24. Storage capacity and fuel on hand:

Type of Fuel	Storage Capacity	Fuel on Hand
diesel	gal.	gal.
propane	lbs.	lbs.
other		

25. Average price of fuel on hand: diesel fuel _____¢/gallons
propane _____¢/pound
other _____

26. Other frost/freeze protection methods used in this grove?

- 1 Yes—►What kind? 1 Permanent Oil Heating System
2 Sprinklers
3 Flood Irrigation
4 Other; PLEASE DESCRIBE: _____

OTHER INFORMATION

27. What other information can you provide that would be helpful in understanding the management of this particular grove?

PLEASE DESCRIBE _____

through ten are concerned with factors such as grove terrain, grove soil type and the presence of large bodies of water which influence a grove's micrometeorology and hence affect frost/freeze protection measures. Again, this information is helpful when comparing and scaling results. A control thermometer located outside of the protected area is important in establishing the temperature profile of a grove which would exist if the protective action were not taken. Therefore, question eleven is designed to determine if control thermometer data may be forthcoming. The last question in this subsection is a rather sensitive one* and therefore it was put at the end so the answer to it would not adversely influence answers to other questions. It concerns the Federal Crop Insurance rating of a grove, which is needed for the classification of groves according to their susceptibility to frost/freeze damage.

The second subset of questions concerns the past and present status of the grove: the month of expected harvest, average yields per acre for the past three years and the estimated yield for the 1976-77 season. The response to question sixteen identifies damage sustained by a grove in the past three years and any additional frost/freeze protection measures this damage may have prompted (question seventeen). Both questions are typical contingency questions** since they are relevant only to a subset of the growers. The second part of question sixteen and question seventeen are contingent upon the "yes" answer to the first part and are answered only by growers who suffered fruit and/or tree damage.

The next subsection of this report deals with the marketing plans a grower may have for the citrus produced in this grove, and the primary reasons for the

* The rate of response to this question was very low. Information was eventually obtained directly from the Federal Crop Insurance Corporation.

** Babbie, E. R., Survey Research Methods, Wadsworth Publishing Co., Inc., Belmont, California, 1973.

plans. Finally, the questions contained in the last subsection concern the frost/freeze technology used in the grove protection. Wind machines and/or heaters of various types, using several different fuels and having different rates of fuel consumption, might be employed. Information on fuel storage capacity and the price of fuel on hand sheds light on the grower's decision-making process, since the amount of fuel and its price plays a role in the decision to protect. The final two questions are concerned with other frost/freeze protection methods which are used for the grove and any other information which the grower thinks would be helpful in understanding the management of this particular grove.

3.4.3 The Grove Background Report Update (Refer to Figure 3.3)

At the beginning of the 1977-78 frost season it was determined that the administration of a second grove background report would be necessary, as long as the growers were willing to provide answers to a few key questions relating to grove management. The background report update was administered by the county extension agents starting in September 1977. It began with three straightforward multiple choice questions relating to expected yield in 1977-78, current marketing plans, and expected month of harvest. The last two questions on the survey form ask the growers to enumerate any changes in frost protection capability since the past season, and to list any errors they have noticed on their 1976-77 year-end reports. Other, more difficult questions relating to frost protection and citrus marketing were considered for inclusion on the background report update; however, it was deemed desirable to minimize the length and complexity of the form as much as possible, so that the growers' willingness to provide further information would not be affected.



One Hundred State Road
Princeton, N.J. 08540
809 924-8778



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Grove I.D.

GROVE BACKGROUND REPORT UPDATE '77-'78

1. What is the expected yield for this grove for the '77-'78
(Please give answer in boxes per acre.)

_____ boxes

2. What are your current marketing plans for this fruit? (Please
circle one answer.)

- 1 Fresh
2 Processed
3 Undecided

3. What is your expected month of harvest for the fruit? (Please
circle one answer.)

- | | |
|------------|-------------|
| 1 January | 7 July |
| 2 February | 8 August |
| 3 March | 9 September |
| 4 April | 10 October |
| 5 May | 11 November |
| 6 June | 12 December |

4. If you have added or removed any frost protection equipment since
last season, please describe below. (For heaters or wind machines,
please give type, number, type of fuel, and fuel consumption rate.)

5. If you noticed any errors in the first section of your season-end
report, please list them below so that we may correct our records.

Page Intentionally Left Blank

3.4.4 Nightly Frost/Freeze Activity Report 1976-77 (Refer to Figure 3.4)

The response to this report was crucial in measuring the cost of frost/freeze protection, the severity of frosts/freezes and, in general, determining the actions growers took on cold nights when frost/freeze protective action was, or was thought to be, necessary.

An introductory paragraph at the top of the 1976-77 form provided the grower with the set of conditions under which the form is to be filled out. A Nightly Frost/Freeze Activity Report was to be filled out for each grove for each day that a fruit frost bulletin by NWS on that day predicted the lowest temperature to be 28°F or less* for the zone in which the particular grove is located, or, if frost/freeze protection measures were undertaken regardless of predicted temperatures. The answers were limited to one grove on one form. A detailed set of instructions accompanied this report.

Responses to the first two questions on the 1976-77 form provided the identification of a grove for which the answers are provided and a date of frost or freeze. Both the names of groves used by growers and the identification number of the grove used in the experiment were required. Answers to questions three and four provided information pertaining to which of the NWS forecasts influenced the grower decision to initiate some kind of protective action and the degree of confidence the grower had in the NWS forecasts.

It should be noted that even if the NWS forecast predicts a cold night, a grower who takes into account the microclimatological conditions may decide not to take any protective measure. The response to question five indicates if a

* An exception was made for growers in Marion County, for whom the trigger temperature was set to be 27°F. The county is located in the southern part of Zone 9 (Figure 2.10). The NWS forecasts are always the same for Zones 8 and 9 and as a result the forecasted lowest temperatures for Marion County are a few degrees lower than the actual measured one.

grower had taken any action associated with frost/freeze protection which incurred costs such as (a) calling in laborers (seasonal or high school students) and paying them wages even if they did not perform any work and were later sent home, (b) asking some members of a permanent staff to perform activities associated with frost/freeze protection (such as monitoring the weather, checking and preparing the equipment, operating the wind machines, etc.) for which they paid beyond and above their regular wages.

Questions six to eleven on the first season's form were contingent upon the "yes" answer to question five. The answers to these questions provided information about labor and fuel costs incurred in the course of undertaking frost/freeze protection measures. Since actual protection costs may be incurred jointly for more than one grove, all costs had to be prorated to the one grove for which the nightly report was prepared. For example, one labor crew may fire and extinguish heaters in several groves of various sizes. Each of these groves may be protected by a different number of heaters requiring different amounts of time for their firing and extinguishing.

The two basic technologies used for frost/freeze protection are wind machines and heaters. Questions seven and eight were concerned with number of wind machines and/or heaters utilized, types of fuel used, fuel consumption rates, and time they were turned on and off. Since both wind machines and heaters of different types may be employed for different lengths of time for the protection of one grove, the concept of a "group" of machines or heaters was used. A group of heaters consists of all heaters of the same type, having the same rate of fuel consumption, and which are turned on and off at the same time. For example, a grove is heated by 40 heaters, 20 are fired at 1:00 a.m. and the remainder are fired at 2:00 a.m. All heaters are extinguished at 6:00 a.m. There are, therefore, two

NIGHTLY FROST/FREEZE PROTECTION ACTIVITY REPORT

Please limit your answer to one grove only (see the instruction sheet for the definition of a "grove" as used in this report). Please answer the following questions only if a fruit frost bulletin by NWS predicted the lowest temperatures to be 28°F or less for the zone in which this grove is located or you had taken any frost/freeze protection during which you incurred costs regardless of predicted temperatures.

1. Your own grove name: _____ grove I.D. number: _____
2. Date of frost/freeze Month: _____ Day: _____
3. Which of the NWS forecasts influenced you to initiate some form of frost/freeze protection? 1 10:15 a.m.
2 4:15 p.m.
3 10:15 p.m.
[CIRCLE ONE NUMBER]
4. On a scale of one to ten, how much confidence do you have in the NWS forecast identified in Question 3?
[CIRCLE ONE NUMBER] no confidence absolute confidence
1 2 3 4 5 6 7 8 9 10
5. On this night, did you take any action which incurred costs (including calling in laborers, paying someone extra to check the equipment, starting wind machines, firing heaters, etc.)?
1 Yes
2 No...GO TO QUESTION 12
6. Labor costs associated with this night's frost/freeze protective action, prorated to this grove:
1 Total direct wages of laborers called in \$ _____
2 Extra direct wages of other personnel to supervise, to monitor weather, check or operate equipment, etc. \$ _____
7. Wind machines:

	Number of Machines	Fuel Type	Fuel Consumption Rate*	Time (hours and minutes)	
				On	Off
Group 1					
Group 2					
Group 3					

*gasoline.....gallons/hour
diesel.....gallons/hour
propane.....pounds/hour
electricity....kilowatts/hour

8. Heaters:

	Number of Heaters	Fuel Type	Fuel Consumption Rate*	Time (hours and minutes)	
				Fired	Extinguished
Group 1					
Group 2					
Group 3					
Group 4					
Group 5					
Group 6					

*diesel.....gallons/hour
propane.....pounds/hour

9. Operating costs of any other used frost/freeze protection method: \$ _____
10. Total approximate mileage incurred during frost/freeze protection travel, prorated to this grove: . . . Trucks: _____ miles
Automobile _____ miles
11. Minimum temperature recorded on the control thermometer for this grove: °F
12. Was there observed any damage to fruit and/or trees not previously reported? 1 Yes....DO NOT FORGET TO FILL OUT A DAMAGE REPORT
2 No
13. If you took no action which incurred costs what were the reasons for not taking it?
1 Weather conditions did not seem to warrant it
2 Market conditions
3 Anticipated protection costs too high
4 Frost previously damaged
5 Started too late—not enough time
6 Took limited action. No additional expense incurred (alerting laborers, having checked equipment at no additional cost, etc.)
7 Other reason; PLEASE EXPLAIN _____

If you have any questions, call your county extension agent.

Figure 3.4 Nightly Frost/Freeze Protection Activity Report 1976-77

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different groups of 20 heaters each. It may take some time to turn on and off wind machines or heaters of the same group. It was assumed that turning them on was done in the same sequence as turning them off and therefore all devices (of the same group) were in operation at approximately the same time. The recorded times on the nightly report were those times at which the first machine or heater in a group was turned on and off, respectively.

The response to the ninth question provided the operating costs associated with other protection methods which could be used (such as overhead sprinkling, flood irrigation, burning of wood, etc.). Another cost is associated with the usage of cars and trucks in transporting personnel and equipment between groves, homes and offices. The response to question ten provided data on mileage incurred as a result of protection measures.

As discussed previously, it is necessary to establish the temperature profile in a grove that would have occurred if protection measures were not undertaken. This is necessary in order to establish the level of frost severity in the grove. This is achieved by adjusting NWS control thermometer data. A final adjustment can be made if the grower has a local control thermometer which records minimum observed temperature. The response to question eleven provided this minimum recorded temperature.

The next question concerned the damage which may have been observed after a cold night. Since there is a separate damage report, the question only called for the grower's attention to this fact, and reminded him to fill out a damage report if he observed any damage to fruit and/or trees.

Finally, if there was no cost-incurring action taken on the part of a grower but the NWS forecast indicated that frost was forecast for the zone within which the grove is located, the grower was asked to circle as many reasons as applicable

for not protecting the grove that night. A list of possible answers was provided in the last question.

3.4.5 Nightly Frost/Freeze Activity and Cost Reports 1977-78
(Refer to Figures 3.5 and 3.6)

From the results of the data collection during the 1976-77 season it was possible to determine several ways in which the collection process could be improved. Several major changes were made to the nightly activity report prior to the second season, reflecting a need to simplify the form further so that less of the grower's time would be required for completing it. Most significantly, the form was divided into two sections, the former bearing the same title as the previous season's activity report, and the latter entitled "Nightly Report of Frost/Freeze Protection Costs."

In part one, the grower is asked to respond to several multiple choice questions relating to all of the groves under his management. Questions three and four, relating to the grower's use of the NWS frost/freeze forecasts, are identical to questions three and four on the previous year's form. Questions five and six ask the grower to list those groves in which he took action and those in which he experienced damage on the night in question. If no action was taken in any grove, question seven lists several reasons for inaction and asks the grower to select those which apply to his decision not to protect. If action was taken or losses were incurred in any grove, part one reminds the grower to complete either the protection cost report or damage report as applicable. If no action was taken or losses incurred, the grower is asked for no further information. Thus, it was possible for a grower to fill out only one form for each trigger night on which he took no action in any grove, rather than a series of forms for each night.

Part two instructs the grower to complete a separate cost report for each grove in which he took action on a given night. Questions two through seven on the



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NIGHTLY FROST/FREEZE PROTECTION ACTIVITY REPORT

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This form can be filled out for several groves at once, if different answers to the questions are not required. Please start a new form whenever necessary.

1. Grove Identification number(s) _____
2. Date of frost/freeze _____
3. Which of the NWS forecasts influenced the grower's decisions on this night?

1 10:15 a.m.

2 4:15 p.m.

3 10:15 p.m.

CIRCLE ONE NUMBER

4. On a scale of one to ten, how much confidence does the grower have in the NWS forecast identified in Question 3?

no
confidence

1 2 3 4 5 6 7 8 9 10

absolute
confidence

CIRCLE ONE NUMBER

5. On the night identified above, did the grower take any action in any of his groves?

1 Yes ... (Indicate grove I.D. numbers) _____

2 No

If action was taken, please fill out protection cost forms for relevant groves.

6. On the night identified above, did the grower experience any damage to fruit or trees not previously reported?

1 Yes ... (Indicate grove I.D. numbers) _____

2 No

If damage was experienced, please fill out damage reports for affected groves.

7. If no action was taken which incurred costs, what were the reasons for not taking it?

1 Weather conditions did not seem to warrant it

2 Market conditions

3 Anticipated protection costs too high

4 Frost previously damaged

5 Started too late - not enough time

6 Took limited action. No additional expense incurred (alerting laborers, having equipment checked at no additional cost, etc.)

7 Forecasted minimum temperature not cold enough

8 Other reason; PLEASE EXPLAIN _____



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Grove I.D. No.

NIGHTLY REPORT OF FROST/FREEZE PROTECTION COSTS

Please fill out a separate form for each grove in which some action was taken.

1. Date of frost/freeze: _____
2. Labor costs associated with this night's frost/freeze protective action, prorated to this grove:
 - 1 Total direct wages of laborers called in \$ _____
 - 2 Extra direct wages of other personnel to supervise, to monitor weather, check or operate equipment, etc. \$ _____

3. Wind machines

	Number of Machines	Fuel Type	Fuel Consumption Rate	Hours of Operation
Group 1				
Group 2				
Group 3				

Fuel codes:

- 1 #2 Diesel
 - 2 Gasoline
 - 3 Liquid Propane
 - 4 Butane
 - 5 Other (please specify)
- _____

4. Heaters

	Number of Heaters	Fuel Type	Fuel Consumption Rate	Hours of Operation
Group 1				
Group 2				
Group 3				

Fuel Codes:

- 1 #2 Diesel
 - 2 Gasoline
 - 3 Liquid Propane
 - 4 Butane
 - 5 Other (please specify)
- _____

5. Operating costs of any other frost protection method: \$ _____
6. Total approximate mileage incurred during frost/freeze protection travel, prorated to this grove:

Trucks _____ miles

Automobile _____ miles
7. Minimum temperature recorded on the control thermometer for this grove (if applicable)

_____ °F

1977-78 cost report correspond directly to questions six through eleven on the 1976-77 activity report, although a few simplifying modifications were made based on the data collection experience gained in the first year. The grower is asked to provide only the total hours of operation for each group of wind machines or heaters rather than the times at which the protection equipment was turned on and off. Fuel codes are provided to assist the grower in specifying the type of fuel used by his equipment, and to ease the job of the coder who transfers information from the completed forms to keypunch codesheets.

The 1977-78 activity and cost reports contain no questions not previously asked and omit none of the questions contained on the 1976-77 activity report. It was hoped that the revisions described would improve grower response in the second and subsequent years of data collection, by eliminating sources of frustration and confusion, and by cutting down on the amount of paperwork required of a grower in the sample.

3.4.6 Damage Reports (Refer to Figures 3.7 and 3.8)

The responses to the questions posed in the damage reports provide a basis for the evaluation of losses suffered by the growers during the frost/freezing nights either to the fruit, or the trees, or both fruit and trees.

The short introduction to the 1976-77 damage report instructed a grower to answer following questions if damage was observed to fruit and/or trees and to limit his answers for one grove to one Damage Report. The response to the first question identified the grove: both the name used by a grower and the identification number used in the experiment were required. The next two questions asked for the date on which a grower completed the report and the date (or dates) of nights which caused the damage. It was expected that the Damage

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DAMAGE REPORT

Please answer the following questions when you observed damage to your fruit and/or trees. Please limit the answers for one grove to one page.

1. Your own grove identification: _____ and grove I.D. number: _____

2. Today's date Month: _____ Day: _____

3. On what night (or nights) was the damage done? Month: _____ Day(s): _____

4. In this grove, was there any damage to the fruit? 1 Yes
2 No...GO TO QUESTION 9

5. How did you intend to market the fruit before the damage? 1 Fresh
2 Processed

6. How do you intend to market the fruit now? 1 Fresh
2 Processed

7. How would you estimate the yield before the damage? _____ boxes per acre
or _____ lbs-solids per acre

8. How would you estimate the yield after the damage? _____ boxes per acre
or _____ lbs-solids per acre

9. Was there any damage to the trees? 1 Yes
2 No...GO TO QUESTION 12

10. If there was damage to the trees, in how many years do you expect full production from this grove? _____ years

11. What is the approximate percentage of the grove which was damaged? _____ percent

12. Would you wish to make any other comment? PLEASE DESCRIBE _____

If you have any questions, call your county extension agent.

Figure 3.7 Damage Report 1976-77



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DAMAGE REPORT-A

I.D No.

Date _____

DAMAGE REPORT -OPlease limit your answers to one grove only.

1. Date of frost/freeze damage
(Use date associated with a.m. hours of the cold night)
2. In this grove, was there any damage to the fruit on the night indicated?
3. How did you intend to market the fruit before the damage?
4. How do you intend to market the fruit now?
5. When did you (or do you intend to) harvest your fruit?
6. How would you estimate the yield before, the damage?
(indicate choice of units)
7. How would you estimate the yield after the damage?
(indicate choice of units)
8. Was there any damage to the trees on the night indicated?
9. If there was tree damage, in how many years do you expect full production to resume?
10. How much of a reduction in total production for the grove do you expect next year?
11. What is the approximate percentage of trees that were damaged?
12. Would you wish to make any other comment concerning damage to this grove?

1. Month: _____ Day: _____
2. 1 Yes
2 No ... GO TO QUESTION 8
3. 1 Fresh
2 Processed
4. 1 Fresh
2 Processed
5. _____
6. _____ boxes per acre, or per grove
_____ lbs-solids per box
7. _____ boxes per acre, or per grove
_____ lbs-solids per box
8. 1 Yes
2 No ... GO TO QUESTION 12
9. _____
10. _____
11. _____
12. _____

This side for county extension agent's records

Report might be completed long after the observation of damage since the extent of the damage may not be measurable until harvesting.

If damage was to fruit only, responses to questions four to eight were required; if damage was to trees only, then responses to questions ten and eleven were required. The response to question four determined if there was any damage to fruit, and questions five through eight were contingent upon a "yes" answer to question four. The marketing plans before the damage, after the damage, and changes in marketing plans were determined from the responses to questions five and six, while the yield of citrus (in boxes per acre for fresh fruit, and pounds-solids per acre for processed fruit) were obtained from the responses to questions seven and eight.

In the case of tree damage, the "yes" answer to question nine led to questions concerning the severity (in the form of the expectation of when the grove will return to full production) and extent of damage (questions ten and eleven). Other grower comments could be made in the space provided in question twelve.

Revisions to the original damage report were made just prior to the 1977-78 season, based on the data collection experience of the first season. Although it was still desirable to have a separate damage report for each grove, the form was streamlined to minimize the time required for completing it. In addition, several questions were reworded to give a clearer indication of the desired response. An additional question was inserted which asks the grower to provide a harvest date for each grove under his management; this information collected by ad hoc methods in the first season, proved very useful to the cost and loss analysis. Since the growers appeared to have some difficulty with completing the original damage report, the revised form was designed for administration by the county extension

agents. It was hoped that this modification in the loss data collection process would yield fewer completed forms with inconsistencies and omissions.

3.4.7 Data Collection Results

Previous sections described the general activity of various participants in the experiment. The collection of frost and freeze protection data was administered by ECON with the active cooperation of the county extension agents. The agents, who maintain constant communication with citrus growers, played a major role in the entire data collection process. This included the selection of participating growers, the distribution of the questionnaires, the collection of completed forms, review of data provided on the forms, and the return of the collected forms to ECON for data processing.

Fifty-two growers managed the 245 groves which were involved in the economic experiment and made up the control group. Some growers managed only one grove involved in the experiment; other growers (mainly the large cooperatives) managed more than ten groves (maximum was 18 groves). The specific breakdown of groves by county is illustrated in Figure 1.6. Each grower was given, at the beginning of the 1976-77 winter season, a three-ring binder containing an introductory page, instructions on how to fill out the Grove Background Reports, Nightly Frost/Freeze Protection Reports and Damage Reports, and an ample supply of all three forms (samples of this material are found in Appendix B and C). At the same time, each grower was sent a letter explaining the purpose and scope of the experiment.

All participating growers were supplied with stamped, addressed envelopes. The growers, after they filled out the questionnaires, mailed them to their county extension agents. The agents were also supplied with stamped, addressed envelopes, and after they gathered all completed background reports or nightly

reports for the time period during which there was a frost or freeze, they sent all the forms to ECON for monitoring and checking of received forms for the completeness, and for further processing.

The mailed-in questionnaire procedure that was used during the experiment had a main advantage in reduced cost. However, it had several disadvantages, mainly a lower rate of response than would have been possible if all the forms were delivered and collected personally; and secondly, some of the questions, which were initially poorly understood, remained unanswered.

These disadvantages were circumvented by using several alternate procedures. First, the agents remained in constant communication with the growers and were able to help them to better understand some of the more complicated questions. Secondly, the two agents whose counties had the largest number of sample groves, namely, Polk and the combined Lake-Orange, received assistance from ECON field representatives. This help was very important, especially after the January 1977 freeze, when in a short period of time a large number of Frost/Freeze Activity Reports had to be collected, recorded and sent out for processing.

The Grove Background Reports were distributed to all the participating growers at the beginning of December 1976, together with instructions on how to complete the forms. The growers were asked to answer all questions and send the completed forms to their agents as soon as possible. It would have been preferable to collect all Grove Background Reports before the first frost or freeze. This was not, however, the case. A large percentage of Grove Background Reports were filled out in December, but a majority of them were returned in January and some even in February.

Since the background reports were essential for a grove to be included in the sample, all groves which were initially selected, but whose background reports were not received, were dropped from the experiment. There were only 10 groves out of 255 which were dropped for various reasons, resulting in the final 245 sample groves. Some growers who initially wanted to participate decided later against the participation; some growers had to withdraw for reasons beyond their control.

The growers were asked to fill out the Nightly Frost/Freeze Protection Activity Reports the day after the frost and/or freeze. Very few growers responded in that manner and the majority of them filled out the forms at a later date when their daily activities allowed them to do so. It should be noted that the accuracy of reports suffered very little, perhaps not at all, since most growers kept rather accurate informal records.

Table 3.4 summarizes the received Activity Reports for the 1976-77 season and indicates the very high response level. The final response was 2,142 reports received out of 2,495 expected, or approximately 86 percent.*

As indicated in the preceding sections, some changes were made in the established data collection procedures prior to the onset of the second frost season, to ensure a continued high response rate, and to alleviate some of the difficulties experienced in the previous year which adversely affected the response rate. In general, the county extension agents (assisted by ECON field representatives) took a more active role in the information-gathering process in the 1977-78 season. In most counties a large percentage of the Nightly Activity and Cost Reports, as well as the Background Report Update and Damage Reports, were filled out by the

* Actually, approximately 300 additional reports were received when they were not anticipated indicating the occurrence of costs on nights when frost was not forecast but was anticipated by the growers.

Table 3.4 Summary of Grower Reports (1976-77)

County	Background Reports		Grove Acreage (Received)	Nightly Activity Reports (Received)																			Damage Reports (Received)
	Planned	Received		11/8	11/22	12/21	1/10	1/11	1/16	1/17	1/18	1/19	1/20	1/21	1/22	1/25	1/29	2/16	2/17	2/20	2/21		
Maricopa	4	4	316	-	-	0/4	-	-	-	3/5	3/4	4/4	3/4	3/4	0/4	-	-	-	0/4	-	-	2	
Highlands	10	10	297	-	-	10/10	-	-	-	10/10	10/10	10/10	8/10	8/10	0/10	-	-	-	7/10	+2	-	10	
Hillsborough	15	15	336	-	-	6/15	+3	+4	-	13/15	11/15	13/15	7/15	7/15	5/15	+3	+3	+1	3/15	+2	+3	7	
Marion	14	14	188	-	-	2/14	14/14	14/14	14/14	7/14	14/14	7/14	12/14	13/14	14/14	+16	14/14	7/14	7/14	+7	+7	59	
Lake	51	51	2175	+8	+9	51/51	50/51	49/51	50/51	33/51	48/51	43/51	50/51	50/51	50/51	+48	42/51	18/51	35/51	-	+34	12	
Orange	38	38	1134	-	-	31/38	38/38	38/38	38/38	37/38	38/38	38/38	37/38	38/38	38/38	+35	24/38	0/38	38/38	-	+20	53	
Osceola	4	4	166	-	-	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	+4	4/4	0/4	4/4	-	+2	12	
Polk	109	109	2644	-	-	100/109	+7	+2	+11	103/109	104/109	104/109	102/109	100/109	95/109	-	-	+2	101/109	+23	+32	137	
Total	245	245	7754	-	-	204/245	106/107	105/107	106/107	210/245	232/245	223/245	228/245	223/245	206/245	-	64/107	25/107	95/245	-	-	287	
Completion (%)		100		-	-	83.3	99.0	98.1	99.0	85.7	94.7	91.0	91.0	91.0	84.1	-	78.5	20.4	79.6	-	-	88%	

Explanation:

- 1) Number of received forms/number of expected forms.
 2) +9...no forms expected, but +9 forms were received. This indicates that some protection costs were incurred even though temperatures were forecast above the "trigger" level.
 3) - Indicates no forms expected or received since temperature forecasts in these counties were above the "trigger" level.

Nightly Activity Reports:

2142 received of 2495 expected (85.8%)

agents or their associates after personal or telephone communication with the growers. This method has several advantages from the standpoint of data flow and clarity of response, and it was actually preferred by most of the agents over the two-step mail-in procedure originally developed. It is expected that this method will be used for any subsequent data gathering related to the experiment.

Table 3.5 summarizes the received Activity Reports for the 1977-78 season, and indicates a continued high response level in the second data collection year. The final response was 2839 reports received out of 3080 expected, or approximately 92 percent.

Damage to fruit and/or trees can be observed after a frost or freeze. Fruit damage can be assessed the following day and, in the case of freshly packed fruit, evaluated in about a week. In the case of processed fruit, the damage to fruit is reflected in the loss of juice, which can be accurately evaluated at the time of delivery of fruit for processing.

Initially, the Damage Reports were supposed to be filled out relatively soon after the frost or freeze event that caused the damage. However, it became clear that Damage Reports, in most cases, would not be forthcoming until after harvest when accurate damage assessments could be made. This meant that, since some citrus was harvested in early summer, Damage Reports were not expected to be completed prior to July. Damage Report completion for 1976-77 did not occur until mid-fall of 1977. Similar delays were encountered in the second project year. However, as with the Activity Reports, a very high response rate was achieved--in 1976-77 287 reports were received out of 327 expected, for a response rate of approximately 88 percent. In the second season, 61 reports were received out of 62 expected, yielding a response rate of approximately 98 percent. Although the high response rates for the Damage Reports were encouraging, the quality of the data

Table 3.5 Summary of Grower Reports (1977-78)

County	Hillsborough	Polk	Orange	Lake	Marion	Osceola	Highlands	Hardee	Totals
Number of Groves	7	93	30	44	14	4	3	4	199
Green Update Forms Received	3	93	30	44	14	4	3	4	195
% of Updates Received	43	100	100	100	100	100	100	100	98
Trigger Days Through March 27	11	11	20	20	25	20	10	10	10-25
Expected Activity Reports	77	1023	600	880	350	80	30	40	3080
Activity Reports Received	90	1025	557	855	216	80	21	40	2884
Trigger Days	75	1023	557	832	215	76	21	40	2839
Nontrigger Days	15	2	0	23	1	4	0	0	45
% of Expected Activity Reports Received	97	100	93	95	61	95	70	100	92
Damage Reports Expected	0	5	14	35	4	2	2	0	62
Damage Reports Received	--	4	14	35	4	2	2	--	61
% Damage Reports Received	--	80	100	100	100	100	100	--	98

received was variable. Pre- and post-freeze fruit yield estimates proved inaccurate in some cases and harvest dates given were often extremely approximate. In other cases, there was confusion as to the proper units for expressing yield, since the dispensation of fruit after a freeze is often complex, with some quality loss leading to a change in market for at least some of the fruit and some deadweight loss. Many growers who completed the Damage Report before their fruit was harvested were unable to give complete or precise answers to some of the questions. A number of growers indicated that tree losses were nearly impossible to assess until months or even years after a major freeze. Thus, most of the problems with the loss data appear to stem from the difficulty of assessing losses, rather than from administrative problems.

After the completion of the 1976-77 control group data collection and analysis, a report was submitted to each of the growers for each of the groves for which he provided data. A sample grower report is given in Appendix B of "Economic Consequences of Improved Temperature Forecasts: An Experiment With the Florida Citrus Growers (Control Group)," ECON Report No. 77-261-1 dated November 30, 1977. The reports contained a summary of all of the grove data as well as county average costs and losses so that the grower could compare grove performance with the county averages. These reports were provided to the growers via the county extension agents.

3.5 Measurement of Grove Temperature Profiles

Heaters and wind machines protect fruit and trees of a citrus grove by increasing the air temperature to levels where the potential damages are minimized. During the operation of the frost protection equipment, the temperature profile of a grove is substantially changed from that which would have occurred if the protection was not undertaken.

The evaluation and comparison of costs and losses experienced by a grower during a night with freezing temperatures requires a determination of a frost severity index, which is related to the temperature profile that would have occurred in a grove if frost protection measures were not initiated.

The following paragraphs describe the data collection procedures and the methods employed during the experiment to determine the temperature that would have occurred in the grove (the unperturbed temperature) if protection measures were not initiated. The importance of this results from the fact that it is necessary to compare costs and losses which are due to the same magnitude or severity of frost. As will be seen, the unperturbed temperature profile plays a major role in the establishment of grove frost severity.

The following methods were used in measuring and establishing grove unperturbed temperature profiles:

- Direct temperature measurement
- Observed grove minimum temperatures and use of NWS thermographs
- Grove shift temperatures and use of NWS thermographs.

The following paragraphs describe briefly how the methods listed above are used in establishing the grove unperturbed temperature profiles and the measurement of the required data.

3.5.1 Direct Temperature Measurements

Not all of the sample groves have control thermometers. When the groves have control thermometers, the thermometers may have either a temperature recording device (thermograph) or may record only a minimum temperature. Grove control thermometers are located outside the heated areas, and thus measure the "true" temperature, insofar as it is uninfluenced by the frost protection activities. A relation between the grove control thermometer and the average (spatial)

temperature in a grove is established in the form of a shift temperature which indicates the temperature difference between a grove (in the absence of frost protection activities) and its control thermometer.

When the control thermometer has a thermograph, the temperature variation during the night is continuously recorded. The shift temperature between control thermometer and a grove is then used to establish the temperature profile for the grove which is thence used to establish the grove frost severity index.

3.5.2 Grove Minimum Temperatures and Use of NWS Thermographs

In the case of a grove control thermometer having only the ability to record minimum temperature, the temperature versus time profile must be obtained by using NWS thermographs and adjusting them to the sample grove by using NWS thermographs and adjusting them to the sample grove by using the measured minimum temperatures in the grove. This assumes that the same temperature versus time pattern would exist in the grove as is measured by the NWS control thermometer; the only difference being a shifting up or down of the whole temperature profile. Thirty-nine NWS control thermometers were selected as being reliable indicators of grove temperatures.

The NWS thermometers which were used were determined by two methods:

- Questionnaire response data from all participating growers determined the NWS thermometer which was used by a grower as a control thermometer for a particular grove.
- Study of grove locations and their proximity to existing NWS thermometers. Each sample grove is then associated with one NWS thermometer. However, one NWS thermometer can be associated with more than one grove.

3.5.3 Grove Shift Temperatures and Use of NWS Thermographs

Unfortunately, most sample groves do not have control thermometers. Because of this, major reliance has been placed upon the use of NWS thermographs and the relationship between the thermographs and the temperatures prevailing in

sample groves has been estimated. For the purposes of the experiment, a set of 39 NWS control thermometers was found to be adequate to reliably represent the grove temperatures. Shift temperature is defined as the difference between a grove's average spatial temperature as a function of time and the temperature at an associated NWS thermometer on a typical radiational frost night. A set of shift temperatures for the groves in the ECON sample was developed prior to the 1976-77 season by Mr. James George, the former meteorologist in charge of the Federal-State Agricultural Weather Service in Lakeland. Mr. George, who has more than 20 years of experience in weather forecasting in Florida, was able to determine both the grove associations with NWS thermometers and the grove shift temperatures based upon his familiarity with the microclimate of the citrus-producing region of central Florida. Table 3.6 illustrates a set of typical shift temperatures between groves and NWS thermometers.

At the end of the 1976-77 frost season, a statistical analysis was undertaken to verify the validity of the shift temperatures. Verification was possible in the case of groves that had reported actual minimum temperatures for several or all of the cold nights on their white Activity Reports. Since these temperatures were presumably read directly from a thermometer in or very near the grove, it was assumed that they accurately represented the true minimum temperatures in the grove on the various cold nights. Given this information, it was possible to develop a statistical "best estimator" for the true shift temperature between the grove and the designated NWS control thermometer. Slightly over one-third of the grove shift temperatures were verified statistically, and of this group 26 proved to be statistically invalid, based on the information available. Table 3.7 lists the groves whose shift temperatures were updated according to the results of the verification.

Table 3.6 Shift Temperatures Between Groves and NWS Thermometers									
NWS Thermometer Number	Sample Grove Number								
	1	2	3	4	5		199	200	...
1	0	-3	0	+1	0		0	0	
2	-2	0	0	0	0		0	0	
3	0		-2				-1		
⋮									
39	0	0	0	0	+1		0	-3	

3.5.4 General Procedure Used in the Determination of Grove Temperature Profiles

The methods used in the determination of grove temperature profiles were described in the preceding sections in a hierarchical order. Direct measurements of grove temperature profile (Section 3.5.1) are preferred to the use of grove minimum temperatures in conjunction with NWS thermographs (Section 3.5.2) and these again are preferred to the use of grove shift temperatures in conjunction with NWS thermographs (Section 3.5.3).

The questions concerning the control thermometers were included in the Grove Background Report (Section 3.4.2). However, the relationship of average grove temperatures and control thermometer measurements and the grower's estimate of grove shift temperatures were determined later during the experiment by a survey conducted at the end of the control group data collection in 1976-77. In addition, minimum temperature information taken from the Nightly Activity Reports in the 1976-77 season was used to update the control thermometer shift factors for a number of groves prior to the 1977-78 frost season. The revised shift

Table 3.7 Groves With Revised
Shift Temperatures,
1977-78 Season

Grove ID	Old Shift	New Shift
3-001	-2	+5.8
3-008	-3	+3.6
5-065	-3	+5.3
5-089	-3	+3.5
5-092	-2	+2
5-093	-2	+4
5-094	-2	+4
5-095	-2	+4
5-096	-2	+2
5-097	-2	+3.7
5-098	-2	+4
5-099	-2	+4.7
5-100	-2	+4.7
5-102	-2	+2.7
5-103	-2	+4
5-104	-2	+4.7
7-009	+2	-2
7-011	+2	-1.4
7-012	+1	-1.4
12-043	-1	+4.9
12-044	-1	+4.9
12-045	-1	+5.1
12-046	-1	+7.1
12-047	-1	+4.7
12-048	-1	+6.9
12-049	-1	+6.6
*NOTE: Associations between groves and NWS thermometers remain unchanged.		

factors rely more heavily on objective measurements than on subjective estimates and thus are expected to improve the precision with which frost/freezing severity is measured.

The general procedure which is followed for establishing grove temperature profiles is illustrated in Figure 3.9. The initial step in the procedure was to establish the association of all sample groves with appropriate NWS thermometers. The next step was to estimate the grove shift temperatures which adjusted the NWS control thermometer to the specific grove temperature data. Next, if it was indicated via the Grove Background Reports that a grove control thermometer was available, grove control thermometer data and their minimum temperatures replaced the previously estimated grove shift temperatures (this procedure was repeated for every frost/freezing night).

3.6 Measurement of Frost/Freezing Severity

An understanding of many natural phenomena is necessary to obtain the damages suffered by citrus fruit and trees as a result of exposure to freezing temperatures (see Appendix A). Microclimate of a citrus tree, dormancy, effects of climate, drought and variety on dormancy and cold hardiness are but some.*

The heat exchange between the tree and the environment can be explained by an understanding of the microclimate of the tree (temperatures of the air, leaf, twig, fruit, bark of trunk and soil). The variation in the climatic properties of the grove can be best described by the variations in the air temperature. Leaf temperatures fluctuate more widely from day to night than do air temperatures; twig temperatures fluctuate about the same as the air; trunk temperatures much less than the air and soil temperatures considerably less than the air.

* Cooper, W. C., R. H. Young and F. M. Turner, Microclimate and Physiology of Citrus: Their Relation to Cold Protection, Agricultural Science Review, Winter 1964.

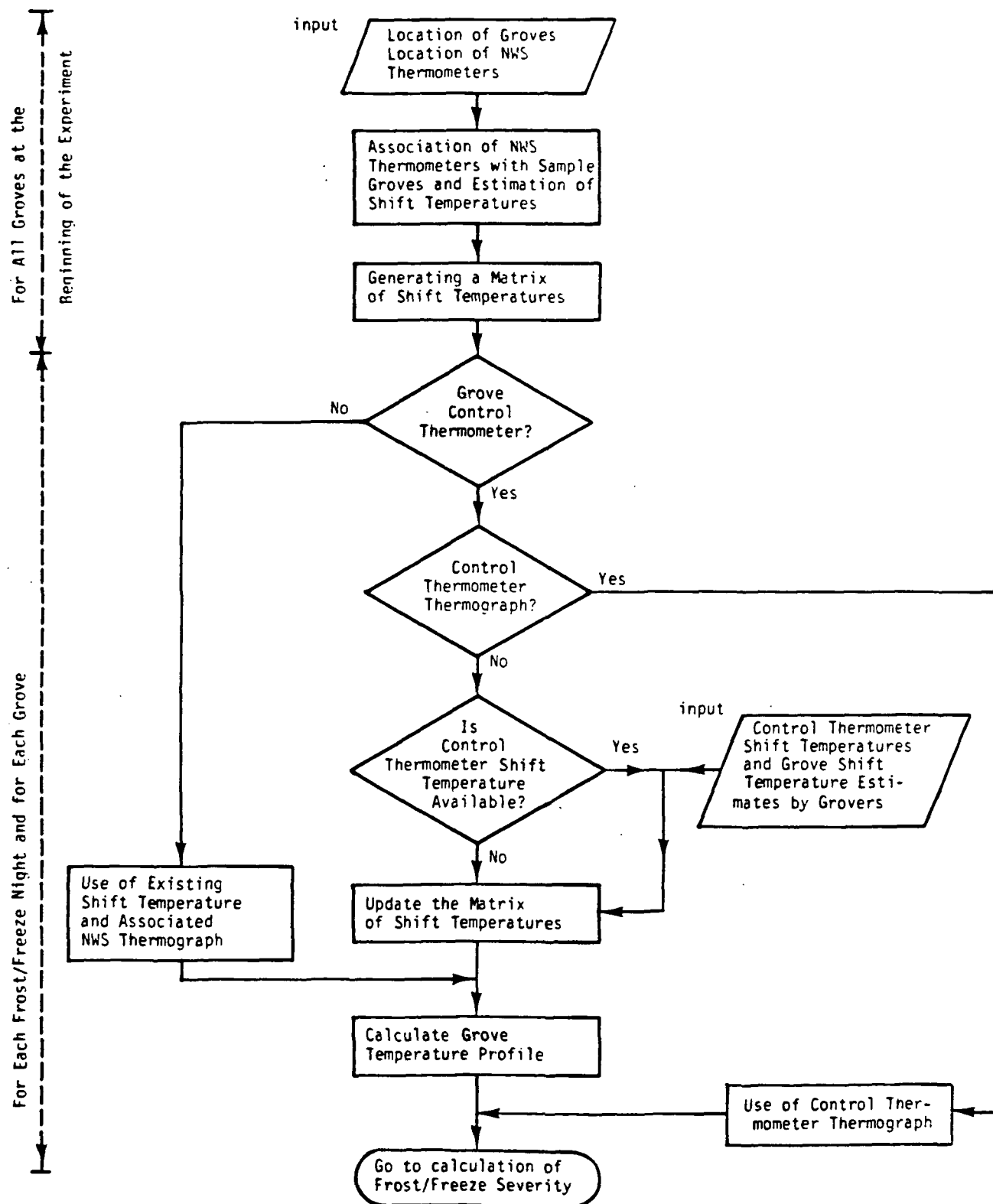


Figure 3.9 Flowchart Diagram of a Procedure Used in Determination of Shift Temperatures for Sample Groves

Dormancy of trees is important in determining the susceptibility to injuries due to freezing temperatures. The winter climate in citrus-growing regions is generally cold for citrus (temperatures around 55°F is the minimum for growth of oranges) and therefore orange trees have only three flushes of growth, occurring in early spring, early summer and late summer, followed by periods of growth interruptions. There is not flush of growth during the winter season and all buds remain quiescent from late fall to early spring. Consistently cold winter weather is beneficial to the dormancy of citrus, which then can tolerate temperature almost as low as 20°F without injury. In Florida, however, the winter temperatures are not consistently low (as they usually are in California) and the unseasonably warm weather in December or January induces a fourth flush of growth. If these warm temperatures are followed by a cold spell then citrus fruit and trees may sustain severe injuries.

Dormancy and consequently cold hardiness vary widely with citrus varieties. For example, trifoliate orange, which develops dormancy earlier in the fall and remains dormant until later in the spring, generally exhibits more cold hardiness in winter, while lemons and limes, which are not dormant and usually grow actively in winter, are very sensitive to cold weather.

Cold hardiness of citrus trees is also increased by moderate drought before winter cold weather, which serves as kind of preconditioning. However, when drought is severe, the tree's food reserves may be greatly reduced by respiration, and the tolerance to cold weather is further reduced.

The physiological factors affecting the cold hardiness of the tree, which depends to a large extent on the winter dormancy, have thus great importance in determining the severity of frosts and/or freezes, especially in Florida with its inconsistent winter weather.

3.6.1 Frost/Freeze Severity Coefficients

The decision to protect a grove from damaging cold is based on detailed and timely knowledge of many variables. Besides the consideration of physiological and phenological factors of citrus described above, there is the grove's microclimate and the expected minimum temperatures, time of occurrence and duration. All of these variables have been extensively studied independently of each other. The complexity of situations increases when more than one variable influenced the decision to protect citrus groves. An attempt to secure a consensus of the temperatures at which citrus requires protection was made in 1974 by the University of Florida's Institute of Food and Agricultural Sciences. A survey of citriculturists and other experts at the University, as well as in the citrus industry at large, obtained estimates of temperatures at which it was necessary to protect the citrus,* in terms of citrus variety, rootstock, time of year, status of trees reflecting previous injuries due to cold, and possibility of a new growth or bloom. The statistical evaluation of the survey (from the University of Florida responses) showed that there can be a considerable variation of the estimated temperatures.

The design of the current experiment requires that a measure of severity of frosts and/or freezes be established so that like events can be compared. The frost severity index utilized in this experiment is a measure of the effect of temperature and its duration on citrus fruit and trees. It was therefore necessary to establish a relationship between temperature and duration of frost/freeze and its severity (which could then be related to costs associated with required protection and damages to fruit and/or trees) while taking into account all the variables described in the preceding paragraphs.

* Gerber, J. I., University of Florida, private communications.

A frost/freeze severity table was therefore constructed which established the relative impact or severity of a frost event in terms of its duration at different temperature levels. Zero implies no damage and ten implies total loss. Two different tables of frost/freeze severity coefficients have been developed; one is related to damage of citrus fruit (Table 3.8) and the other to damage of citrus trees (Table 3.9). Separate tables of relative impact of temperatures and durations have been developed since trees can tolerate much lower temperatures than fruit without sustaining any damage or requiring any protection.

A further differentiation of the severity measures exists for each different citrus variety. Grapefruits, for example, can tolerate, on the average, at least one degree (for a given duration) colder temperatures than oranges, while specialty fruit can tolerate temperatures one-half degree (average) warmer than oranges. As far as trees are concerned, the dependence of severity measures on variety is not as significant as dependence on the time of the season and damages suffered during previous frosts. During the months of January and February, trees are generally dormant and can tolerate at least one degree (for a given duration) colder temperatures than those shown in Table 3.9. However, if there was a period of unusually warm weather and a green flush of growth occurred (usually in February and March) then trees can tolerate, on the average, temperatures three degrees higher than they would otherwise. A similar situation occurs if trees were injured during previous frosts or freezes in the same season (or very seriously injured during the previous season). Their cold temperature tolerance would be reduced on the average by one degree.

Tables similar to Table 3.8 were developed for specialty fruit and grapefruits by adjusting the critical threshold up for the specialty fruit and down for grapefruit.

Table 3.8 Relative Severity Measure of Frost/Freeze for
Early and Midseason Oranges*

Temp. [°F]	Hours At A Given Temperature											
	1	2	3	4	5	6	7	8	9	10	11	12
28	0	0	0	0	0.5	0.75	1	1.25	1.5	1.75	2	2
27	0	1	2	2	3	4	4.25	4.5	4.75	5	5	5
26	0	1	2	3	4	4.3	4.6	5	5	5	5	5.5
25	1	2	3	4	4.5	5	5.2	5.4	5.5	5.7	5.85	6
24	1.5	2.4	4	4	4.5	5	5.3	5.7	6	6.5	7	8
23	2	2.7	4	4.1	5	6	7	7.5	8	9	10	10
22	2.5	3	4	5.5	7	8	10	10	10	10	10	10
21	3	3.5	5	6.5	8	10	10	10	10	10	10	10
20	4	5	6	8	10	10	10	10	10	10	10	10
19	4.5	6	7.5	9	10	10	10	10	10	10	10	10
18	5	7	9	10	10	10	10	10	10	10	10	10

* Estimates provided by Dr. J. Gerber and Dr. J. Bartholic of the University of Florida.

Table 3.9 Relative Severity Measure of Frost/Freeze for Trees*

Temp. [°F]	Hours At A Given Temperature											
	1	2	3	4	5	6	7	8	9	10	11	12
28	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
24	0	1	1	1	1	1	1	1	2	2	2	2
23	1	1	1	1.2	1.5	1.75	2	2.2	2.4	2.6	2.8	3
22	1.3	1.6	1.8	1.9	2	2.3	2.6	2.9	3.2	3.5	3.8	4
21	2	2	2	2	3	3	3	3	3.5	4	4.5	5
20	2.5	2.75	3	3.3	3.6	4	4.3	4.6	5	5.6	6.3	7
19	3	4	5	5.5	6	6.3	6.6	7	7.5	8	9	10
18	4	5	6.5	8	9	10	10	10	10	10	10	10

* Estimates provided by Dr. J. Gerber and Dr. J. Bartholic of the University of Florida.

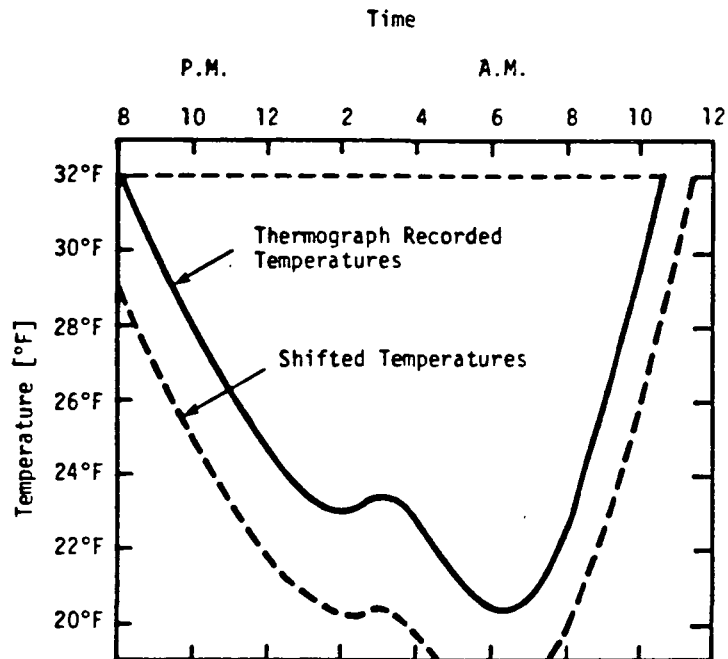
3.6.2 Use of Severity Coefficients in a Classification of Weather Events

The severity coefficients for both fruit and trees, adjusted for variety, are used to establish a frost severity index for every grove in the sample and for every cold weather event.

Control thermometers to be used throughout the experiment were selected according to their proximity to groves in the sample and the reliability and accuracy of the data. Thermograph traces from all NWS control thermometers in central Florida are kept on file at the Federal-State Weather Service Office in Lakeland. Through the cooperation of the National Weather Service, ECON was able to obtain copies of all needed thermographs (those control thermometers registering a temperature of 32° or less on a given night). Although these reproductions are not of the highest quality, in most cases they were adequate for determination of durations of cold temperatures on each frost/freeze night.

Frost nights are selected according to both the forecasts before the event, and the observed minimum temperatures at the control thermometers selected. Both sets of data are provided on a regular basis by the Florida National Weather Service personnel. In this way, it is made certain that severity coefficients for all cold and predicted cold nights (when a grower may have taken cost-incurring action) will be calculated. This includes "false alarms" and "no-warning" freezes.

The specific procedure for establishing the grove severity index is illustrated in Figure 3.10. Once the durations of cold temperatures for each control thermometer on each cold night have been recorded, the shift coefficient matrix is used to adjust the control thermometer temperature profiles to obtain a profile for each grove in the sample. For each temperature and duration within a grove profile, a severity coefficient is obtained from the tables of coefficients for fruit and trees. These coefficients are then summed to achieve the value of the grove's severity index for this particular frost event.



Temperature Range, °F	Measured Duration, Hours	Shift Temperatures	Adjusted Duration, Hours	Duration at Temperature	Severity Coefficients (Fruit & Trees)
32-31	14				0
31-30	14				0
30-29	13				0
29-28	12		14		0
28-27	12		14	0	0
27-26	10		13	1	0
26-25	10		12	1	0
25-24	10	-3°F	12	0	0
24-23	7		10	2	3.4
23-22	4		10	0	0
22-21	2		10	0	0
21-20	1		7	3	7
20-19			4	3	9
19-18			2	2	10
18-17			1	1	9
Weighted Severity Index for Grove					38.4

Figure 3.10: Sample Calculation of Frost/Freeze Severity Index Based Upon a Typical Thermograph

Figure 3.11 illustrates the overall process of severity index determination, based upon a typical thermograph record.

The following steps are indicated:

- Control thermometer selection
- Frost/freeze night selection
- Recording of control thermometer temperature profiles
- Adjustment of temperature profiles according to shift coefficients
- Use of severity coefficients to calculate severity index for fruit and trees in each grove
- Grove frost severity index input into the economic analysis.

3.6.3 Measurement of Susceptibility of Groves to Frost/Freeze Damage

A classification of groves according to their susceptibility to frost/freeze damage is very desirable in studying the economic benefits of improved weather forecasting. It is particularly useful when scaling results from the sample population to the target population. The frost susceptibility of a grove depends on many factors such as the location, the terrain and the local microclimate, the type of fruit, the grove management techniques and the use of frost protection technology.

The Federal Crop Insurance Corporation of the U.S. Department of Agriculture determines the frost/freeze susceptibility of all lands which it chooses to insure. The FCIC indicates their assessment by assigning letters A (the least susceptible) through E (the most susceptible) to each grove. Ideally, the FCIC code provides an assessment of the land only, depending on the grove location, the type of terrain and the local microclimate. However, in actual practice, the fruit type, frost protection methods and management techniques are considered as well in the FCIC determination of its premium schedule.

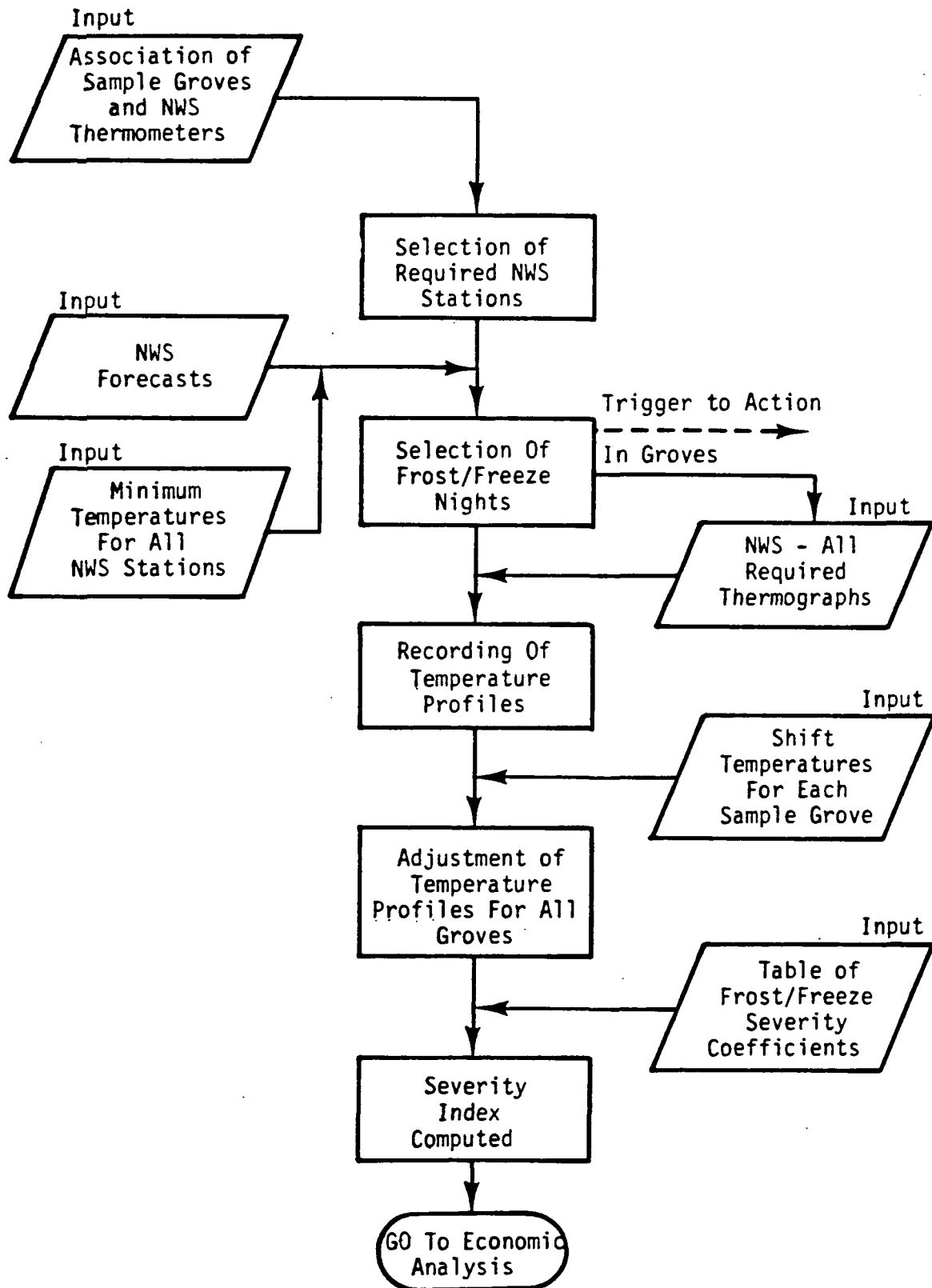


Figure 3.11 Development of Frost Severity Index for a Classification of Weather Events

Initially, determination of the code for any particular grove depends on observations of the terrain by an experienced FCIC representative who inspects the grove. The codes are revised at regular intervals and may be changed based on the frost history of a grove and surrounding areas, and the current condition of the land.

The premium structure is set to reflect the fact that certain types of fruit are more easily damaged than others by frost and/or freeze. Thus, premiums paid to insure tangerines and tangelos will ordinarily be higher than those paid to insure grapefruits or early and midseason oranges. The rate structure also reflects suitability of fruit grown to terrain and location; thus, it may cost more to insure fruit on A-rated land in one country than in another.

It is necessary to obtain the FCIC classification code of each of the sample groves of the experiment. All counties with groves which are part of the experiment are covered by FCIC. The Grove Background Report (Section 3.4.2) attempts to obtain the FCIC classification of the grove from the grower. If the code is not determined directly in this manner, then the FCIC records can be used.

The FCIC maintains detailed records in the form of actuarial maps, with dashed lines indicating the division between areas with different susceptibility codes. Yearly update sheets are included, listing any changes by section, subsection, and occasionally by owner. Each actuarial map contains four sections (2560 acres or 4 square miles); given a grove's location (section, range and township), it is usually possible to determine which code is to be applied. Complications arise when the land in a particular section has more than one classification. In such cases, any additional information about the grove (size, shape, type of fruit grown, proximity to roads and bodies of water, etc.) is useful. The FCIC has in the past kept up-to-date ownership maps which aid in locating the

particular grove within its section. These are now considerably out of date, but are still occasionally useful. Figure 3.12 illustrates the determination of the FCIC code for a grove in the sample, using both the actuarial and property maps.

By following the procedure outlined above, ECON was able to determine the correct FCIC susceptibility code for more than 65 percent of the groves in the sample. In order to unambiguously determine the FCIC codes for the remaining groves in the sample, pinpoint locations for these groves were needed. This information was collected from the cooperating county extension agents and from the growers themselves during the 1977-78 frost season. With this additional data it was possible to determine the correct FCIC codes for nearly all of the remaining groves.

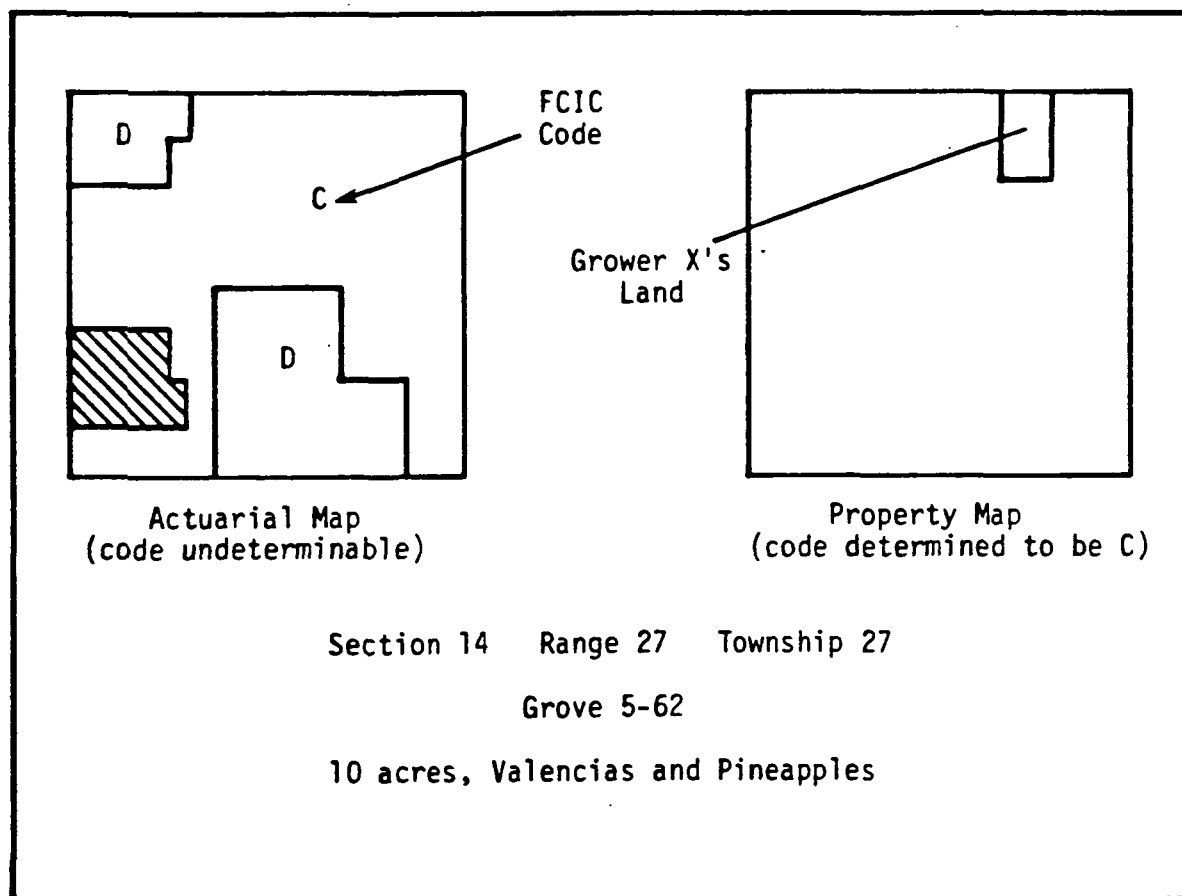


Figure 3.12 Determination of FCIC Grove Classification

4. FORECAST VERIFICATION

4.1 Introduction

Fruit frost forecasts are issued by the National Weather Service office in Ruskin, Florida three times each day during the cold season, which begins sometime in November and ends in late February or early March. The forecasts give estimated expected minimum temperatures for the coming night for each of 23 zones in the state of Florida. The minimum temperature forecasts are not point estimates but rather four (sometimes five or six) degree ranges; this makes the forecasts more flexible and accounts for some of the temperature variations within zones on any particular night.

The first forecast of the day is made at 10:15 a.m., based on the best information available to the agricultural meteorologists. Updates and refinements are made at 4:15 p.m. and again at 10:15 p.m. Since citrus growers must in general make their protection decisions before dark, the 4:15 forecast is more heavily relied upon than its later counterparts. A 4:15 p.m. forecast for January 19, 1977 is given in Table 4.1.

In addition to minimum temperature predictions, from time to time the forecasts also include information about frost, precipitation, winds, movement of weather fronts and expected duration of below-freezing temperatures. This information is provided when it is deemed helpful to growers in making careful decisions about frost protection.

Forecast verification is a term which denotes any sort of analysis to determine the absolute or relative accuracy of a forecast or set of forecasts. Generally, statistical methods are used to objectively verify temperature forecasts

Table 4.1 Frost/Freeze Forecast Facsimile

PENINSULAR FLORIDA FARM AREA MINIMUM TEMPERATURE FORECAST
 NATIONAL WEATHER SERVICE TAMPA BAY AREA RUSKIN FL
 4 15 PM EST WED JAN 19 1977

FREEZE WARNING ALL AREAS TONIGHT

TONIGHT..CLEAR AND COLD. NORTHWEST WINDS DIMINISHING OVERNIGHT WITH PERIODS OF CALM POSSIBLE AFTER MIDNIGHT. TEMPERATURES FALLING STEADILY THROUGH THE NIGHT WITH LOWS TO OCCUR BETWEEN 5 AM AND SUNRISE.

LOWEST TEMPERATURES

ZONES 6 7	10 TO 14
ZONE 8	12 TO 16
ZONE 9	14 TO 18
ZONES 10 12	18 TO 22 WITH 16 TO 18 COLD POCKETS
ZONE 11	16 TO 20 WITH 14 TO 16 POCKETS AND MUCKLANDS. SCATTERED FROST
ZONES 13 14 15 16	20 TO 24 WITH 16 TO 20 POCKETS. FROST
ZONE 17	22 TO 26 FROST
ZONES 18 19 INCLUDING IMMOKALEE	22 TO 26 WITH 20 TO 22 BACKLANDS. FROST
ZONES 20 21	24 TO 28 FROST
ZONE 22	26 TO 30 EXCEPT 28 TO 32 ALONG THE COAST. FROST

TEMPERATURE OUTLOOK...CONTINUED COLD WITH FREEZING TEMPERATURES AGAIN MOST FARMING AREAS FRIDAY MORNING.

issued by the National Weather Service. Verification of the fruit frost forecasts serves a dual purpose with respect to the Florida experiment. Verification is necessary first to determine whether changes in forecast accuracy would preclude the combining of data collected in 1976-77 and 1977-78 into a common control group data base. Second, as discussed in Section 3.2.4, it is necessary to establish the probability distribution of forecast error for use in the final normalization of costs and losses to a standard weather year. This requires the development of forecast accuracy measures which will indicate the impact of improved forecasting capability.

Actual minimum temperatures are recorded at over 100 weather stations throughout the state. Since the groves in the ECON sample are located in central Florida in zones 9, 11, 13, 14 and 15, consistently-reporting stations from those areas were selected to provide the data for verification. Table 4.2 shows the number of thermometers used in each zone, as well as the number of "verification nights" in each of the last two seasons. A "verification night" is defined as any night when either a forecast was issued with a minimum temperature of 32°F or

Table 4.2 Data Available for Fruit Frost Forecast Verification			
Zone	# of Thermometers	# of Nights 1976-77	# of Nights 1977-78
9	8	32	47
11	12	28	35
13	18	15	23
14	19	15	22
15	14	14	20

below, or at least one of the selected thermometers in a zone actually registered 32°F or below.

During the past two frost seasons, ECON has collected all of the fruit frost forecasts issued by the Ruskin Weather Service office. Because of the importance of the 4:15 p.m. forecasts to the citrus growers, it was decided that this set of forecasts would be used for the statistical verification. Minimum temperatures for the selected stations were collected from the Federal-State Weather Service office in Lakeland, Florida. A very few minimum temperatures were estimated by an agricultural meteorologist familiar with the area and with the particular stations for which observations were missing.

4.2 Methodology

The term "forecast verification" as it is used here denotes a statistical analysis of forecast errors, where a forecast error is defined to be the difference between the forecasted and actual temperature at a particular location. In terms of the fruit frost forecasts,

$$d_{ijk} = (F_{ijk} - A_{ijk}),$$

where

d is the temperature difference or temperature forecast error

F is the forecasted temperature

A is the observed or actual temperature

i is the subscript for control thermometers

j is the subscript for verification nights

k is the subscript for forecast zones.

Before discussing specific measures of forecast accuracy or usefulness, it is necessary to identify in a precise way those attributes of the fruit frost forecasts

which are desirable to the citrus grower. Data from citrus experts, nightly frost/freeze protection activity reports and direct interviews with growers indicate that growers are little concerned with forecast errors when temperatures are generally above freezing, but that forecast errors do become critical at lower temperatures. Some experts have suggested that overforecasting the cold is a less serious error than issuing a forecast that is warmer than the resulting actual temperatures. At this time, however, further study is needed to verify this hypothesis. It is more readily apparent that, with regard to minimum temperatures, forecast accuracy during the spring, summer and autumn months in Florida is of little consequence to the citrus growers. These considerations support the logical decision to verify forecasts only in those cases where forecast accuracy could have had some measurable impact on the citrus grower's protection decision.

Once the difference between forecasted and actual minimum temperature has been evaluated, it is possible to define several different performance measures or scores. The mean square error

$$MSE_k = \frac{1}{n} \sum_{i,j} d_{ijk}^2 \quad (n = \text{number of observations})$$

and bias or mean algebraic error

$$B_k = \bar{d}_k = \frac{1}{n} \sum_{i,j} d_{ijk}$$

are commonly-used verification statistics for minimum temperature forecasts like the Florida fruit frost bulletins. Similar statistics currently used by the National Weather Service include mean absolute forecast error:

$$MFE_k = \frac{1}{n} \sum_{i,j} |d_{ijk}|$$

and percent forecast errors in several classes:

$$T1 = 100 \times (\text{number of 0 to 5 degree temperature errors}) / (\text{total number of temperature forecasts})$$

$$T2 = 100 \times (\text{number of 6 to 10 degree temperature errors}) / (\text{total number of temperature forecasts})$$

$$T3 = 100 \times (\text{number of 11 to 15 degree temperature errors}) / (\text{total number of temperature forecasts})$$

$$T4 = 100 \times (\text{number of greater than 15 degree temperature errors}) / (\text{total number of temperature forecasts}).$$

Each of these performance measures has its adherents among meteorologists and climatologists involved with forecast verification. The mean square error is probably the most commonly used verification "score;" however, this statistic is valid as a measure of accuracy only when the forecast errors prove to be approximately normally distributed with zero bias. When there is some measurable bias, the mean square error reflects both the bias and the dispersion of the calculated differences, and it is impossible to separate these two effects.

The Florida fruit frost forecasts are verified each spring at the Federal-State Weather Service office in Lakeland, Florida. The verification scheme currently used is based on the definition of a "bullseye" forecast as one where the actual temperature at a control thermometer fell in the predicted four degree range. A "good" forecast is defined as one where the observed minimum temperature is within two degrees of the forecast range. Only observations from "cold nights" (nights when the minimum temperature fell below 36°F somewhere in a zone) are used. A histogram of forecast errors is prepared, and the mean algebraic forecast error (bias) and variance are calculated. Figure 4.1 is an example of a verification histogram prepared by the Florida NWS. The previously mentioned definition of zero error ("bullseye forecast") leads to a huge central spike in the histogram which is somewhat misleading. Statistical tests are not routinely performed, and no

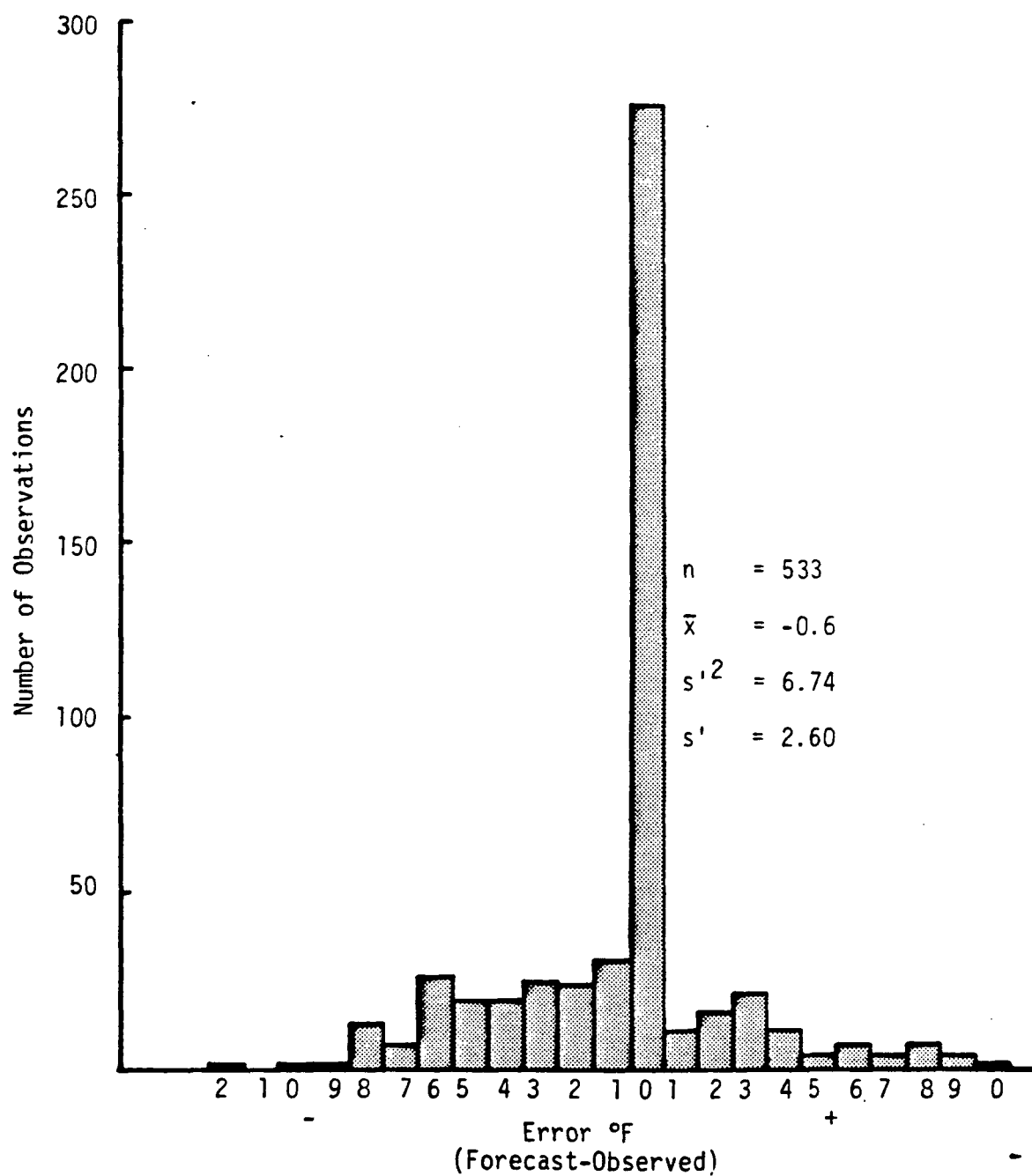


Figure 4.1 Distribution of Forecast Errors for the 31 Stations in the Bartow District for the Four-Month Period, December 1975-March 1976 for 41 of 44 Cold Nights

methodology has been developed for comparing distributions of forecast errors from two different seasons.

An improved evaluation scheme for the fruit frost forecasts in Florida must test in a more direct way the use of the system by the citrus growers who make up the primary target group. In addition, it should be precise enough to sense small changes in forecast accuracy due to new prediction methods or the introduction of new technology (such as the SMS/GOES data). Finally, it should include a number of statistical tests, so that more valid conclusions can be drawn from the numerical results. The development of histograms of forecast errors is useful for determining whether or not the d_{ijk} follow a normal distribution. If the errors are skewed or follow some non-Gaussian distribution, it is necessary to compare the distributions themselves in order to draw reasonable conclusions relating to changes in forecast accuracy.

Since the forecasts are issued with four degree minimum temperature ranges, it is necessary to arrive at a "point forecast" for each control thermometer in order to calculate the forecast errors. As discussed earlier, the NWS meteorologists in Florida use the top or bottom of the forecast range as the "point forecast" for each thermometer, depending on whether the actual temperature falls above or below the forecast range. A less artificial method consists of simply taking the midpoint of the forecast range and using that temperature as the forecast for all thermometers in the zone on a given night. However, the forecasts are issued with a temperature range for a reason: observed temperatures across a zone generally vary by at least four degrees, with ten or fifteen degree variations not uncommon. Most of these variations are caused by microclimate factors such as altitude, the presence of large bodies of water, the prevailing winds, etc. An experienced grower located in a valley near a particular control thermometer can generally

expect temperatures at that spot to fall at the low end of the forecast range. A similar grower located on the downwind side of a large lake will in most cases experience slightly warmer temperatures than the forecast might indicate. In addition, there are probably a number of locations in each zone in which the various microclimate factors cause the observed temperatures to fluctuate around both sides of the forecast range.

One way to determine whether there is a consistent pattern of observed temperatures in a zone relative to the forecast range is to undertake a statistical analysis using historical data. A straightforward way to estimate thermometer "shift" factors is to perform a least-squares analysis using multiple regression techniques. The basic model used is

$$T_{ijk} = F_{jk} + u_i + e_{ijk}$$

where

F is the zone forecast

T is the actual minimum temperature at a particular thermometer

u is the thermometer shift factor

e is a random error term (assumed to be normal and independently distributed with zero mean).

For example, suppose the estimated shift factor (u_i) for a thermometer in zone 9 is -3°F . Assuming random error to be zero (its mean value), on a night where the forecast midpoint is 28°F , the expected actual minimum temperature at the thermometer, as predicted by the regression equation, is $28^\circ + (-3^\circ) = 25^\circ\text{F}$.

The variables are actually estimated using the two years of collected data by the inclusion of a 0-1 (dummy) variable for each thermometer. The variables are estimated separately for each zone. The results include a forecast shift factor for each thermometer and a t-statistic for each estimated factor. The t-statistic (or

significance statistic) is calculated by dividing the estimated shift coefficient u_i by its standard error $s/\sqrt{n}$, where s represents the sample standard deviation of the regression coefficient and n the sample size. A simple statistical test is used to determine whether or not each factor is statistically significant, based on the null hypothesis that the factor does not differ significantly from zero. Since the significance statistic is known to follow the student's t -distribution with $n-k-1$ degrees of freedom (where k is the number of factors estimated in the regression), consulting the appropriate t -table yields the critical point for the hypothesis test. If the observed t -statistic is greater than the critical point, the null hypothesis must be rejected. If the critical point is not exceeded then there is no evidence to suggest that the estimated factor is significantly different from zero.

After completion of the hypothesis tests, those factors that are significant are applied to each forecast midpoint additively to create point forecasts tailored to the particular thermometer. Thus, the final adjusted differences are calculated by means of the equation

$$d_{ijk} = ([F_{jk} + u_i] - A_{ijk})$$

where F , u and A are as previously defined. When a thermometer shift factor is not significant, the adjusted differences and the raw differences coincide for that particular location. The use of adjusted differences (based on forecasts tailored to the individual thermometer location) rather than raw differences (based on zonewide forecasts) is intended to approximate, as closely as possible, the actual way in which zone forecasts are subjectively adjusted by citrus growers to arrive at an expected minimum temperature for their particular location.

Once a complete set of adjusted differences has been calculated for a zone, a bias and variance for the resulting distribution are computed. Statistical tests are

then used to determine whether or not the biases from the two different years differ significantly, and whether or not the variance has decreased due to improved information in the season.

To test whether the bias or mean error in a zone has changed over time, it is necessary to set down the null hypothesis that the two biases are equal. That is,

$$\mu_1 - \mu_2 = 0$$

where

μ is the true bias or mean error

the subscript 1 represents the 1976-77 season

the subscript 2 represents the 1977-78 season.

The ordinary method of finding confidence limits and making tests of significance for the difference between the means of two independent samples assumes that the two population variances are the same. When there is some doubt about the equality of the two variances, it is necessary to replace the ordinary t-statistic for a test of this type with the quantity

$$t' = (B_1 - B_2) / \sqrt{s_1^2/n_1 + s_2^2/n_2}$$

where

B is the sample mean

s^2 is the sample variance

n is the sample size

the subscripts 1 and 2 are as previously defined.

This quantity does not follow the Student's t-distribution. Two different forms of the distribution have been worked out, both requiring special tables. However, an approximation has been developed which uses an ordinary t-table and is sufficiently accurate for the purpose at hand. To carry out the two-tailed significance test, it

is necessary to calculate t' and then to determine the critical point by evaluating the expression

$$(w_1 t_1 + w_2 t_2) / (w_1 + w_2)$$

where

$$w = s^2/n$$

t_1 and t_2 are points of the t-distribution for n_1-1 and n_2-1 degrees of freedom respectively

s^2 is the sample variance

n and the subscripts 1 and 2 are as previously defined.

Again, if the observed t' is greater than the critical point, the null hypothesis must be rejected; otherwise it is concluded that there is no evidence to suggest that the biases from the two seasons are significantly different.

One way to determine whether the variance of the forecast errors has changed significantly from season to season is to conduct a one-tailed F-test under the null hypothesis that $\sigma_1^2 = \sigma_2^2$ (where σ^2 represents the true variance of each distribution.) The alternative hypothesis in this case is $\sigma_1^2 > \sigma_2^2$; that is, that the variance has declined significantly. The test statistic is

$$F = s_1^2 / s_2^2$$

and the critical point for n_1-2 and n_2-2 degrees of freedom is found by consulting the appropriate table. If the observed F-ratio is greater than the critical point, the null hypothesis is rejected in favor of the alternative hypothesis. If not, the null hypothesis is left to stand.

If the second season's variance is obviously larger than the variance in the first season, it is advisable to use $\sigma_1^2 < \sigma_2^2$ as the alternative hypothesis in the one-tailed test. In that case, the F-statistic is inverted, and the test determines whether there has been a statistically significant increase in variance from year to year.

4.3 Forecast Verification Results

Table 4.3 presents an overview of the results of the forecast verification procedure discussed above. A detailed summary of the statistical results of the two-season forecast verification is given in Appendix D of this report. A review of the statistical results shows a significant change in forecast bias only in zone 15, where the bias changed sign from negative to positive but remained close to zero, and in zone 13, where the sign change was in the opposite direction. There was a nearly significant decrease in variance in zone 9, but in zones 13, 14 and 15 the forecast error variance actually increased significantly.

Overall, the data display no convincing pattern of change from season to season. The most reasonable conclusion to draw from the results presented above is that the accuracy of the fruit frost forecasts has remained approximately constant over the time period considered. Thus, there is no reason to separate the data collected in 1976-77 from that collected in 1977-78; both may be combined into a common control group data base. The finding that there has been no significant improvement in forecast accuracy over the two seasons is not surprising, since the meteorologists who made the forecasts reportedly did not routinely use the SMS/GOES data in either season.

In the next season, it is more likely that the forecast accuracy will change consistently, although it will be somewhat difficult to separate the effect of improved information from that of other factors, such as an impending change in staff. The results of a further verification will also depend on the extent to which the meteorologists in Florida use the SMS/GOES data in preparing their daily forecasts during the 1978-79 cold season. Figure 4.2 shows a set of histograms which approximate the probability distributions of raw forecast error for use in the first normalization of costs and losses to a standard weather year. In the

Table 4.3 Overview of Forecast Verification Results		
Zone	Significant Change in Bias?	Significant Change in Variance?
9	No	No
11	No	No
13	Yes--decrease and sign change (+ to -)	Yes--increase
14	No	Yes--increase
15	Yes--increase and sign change (- to +)	Yes--increase

histograms, each asterisk represents three observations in a zone; each observation is the forecast midpoint minus the observed minimum temperature at a particular thermometer on a particular night during the 1976-77 or 1977-78 season. Although the distributions differ from zone to zone, it is notable that each is roughly normal. Further data from additional seasons may be used to smooth the histograms so that they better represent the underlying probability distributions, provided that the data is from seasons with approximately similar forecast accuracy. If a major change in forecast accuracy is seen in the 1978-79 season new and possibly quite different distributions of forecast error will result.

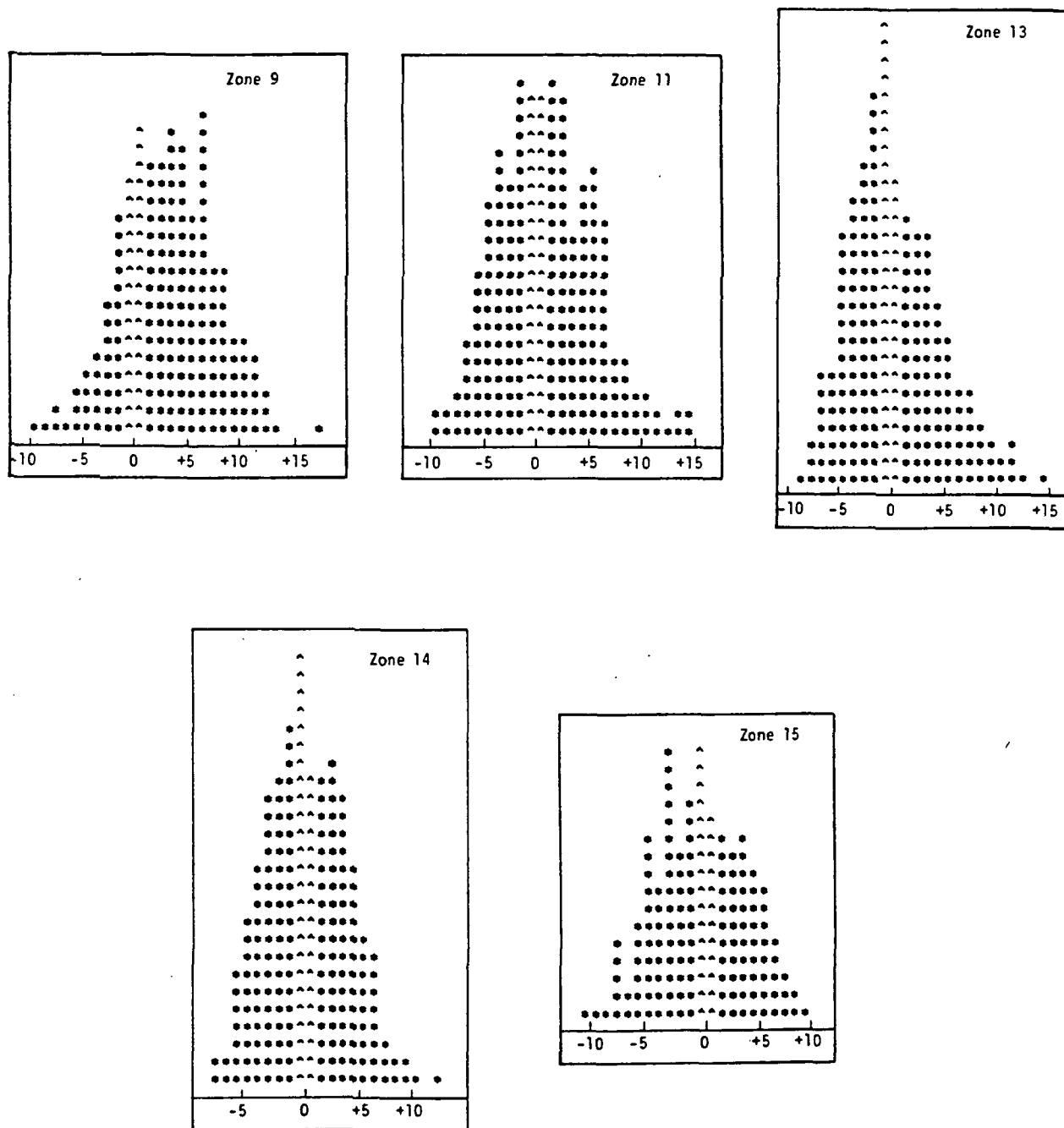


Figure 4.2 Histograms of Forecast Error

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5. ANALYSIS OF COSTS AND LOSSES

This section takes, as its beginning point, the grower-supplied data pertaining to costs and physical losses from freeze nights (nights which triggered Nightly Frost/Freeze Protection Reports; see Section 3.4.4, 3.4.5 and 3.4.6), weather event characteristics (see Section 3.5) and grove characteristics (see Section 3.4.2). The outputs generated by the work discussed in this section are several. The first is simply a statistical report of economic costs and losses from freezes and freeze warnings for the sample groves, for the 1976-77 and 1977-78 control years; this is reported in Section 5.5. An intermediate, but important, output is the statistical relationship between weather event severity and economic costs and losses, based upon the 1976-77 and the 1977-78 experiment results; it is the hypothesis of this experiment that this relationship will change as a function of the accuracy of the weather forecasting system. Thirdly, using the relationship between weather and economic costs and losses and using historical weather data for the years 1937-66, costs and losses for these years are simulated and reported in a second statistical report. By comparing this second report, generated from data gathered in the control years (1976-77 and 1977-78), with similar reports generated in the experiment test group year(s), a measure of the expected savings and benefit from the forecast improvements will be obtained.

Figure 5.1 serves as a flowchart reference for the material discussed in this section.

5.1 Analysis of Frost Protection Decision Making*

Like all economic decisions, the grower chooses the course of action which yields the greatest utility. This experiment is concerned with the situation where

* For more detail, see "A Plan for Application System Verification Tests--The Value of Improved Meteorological Information," Vol. I, ECON Report No. 76-108-2, August 1976.

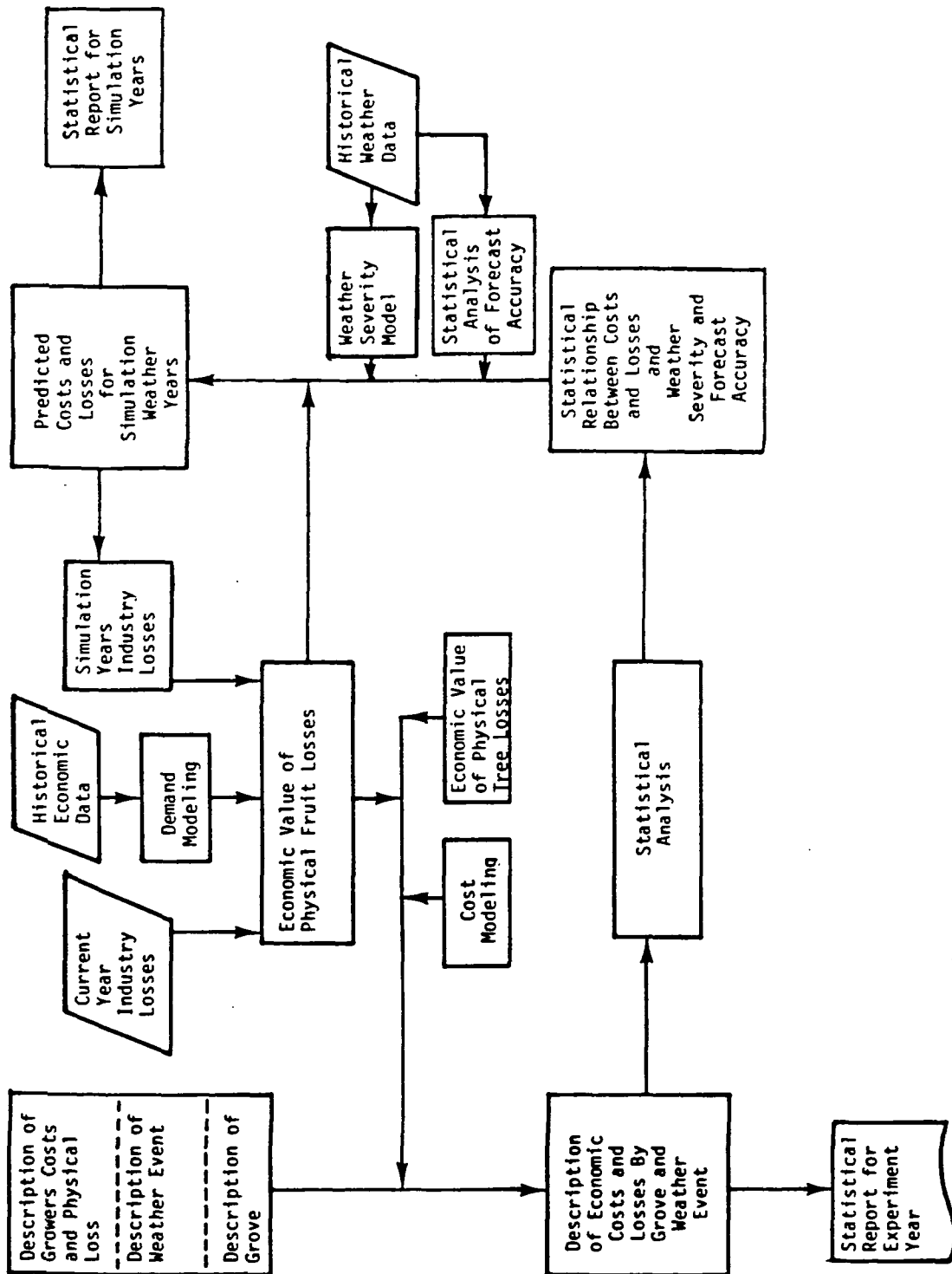


Figure 5.1 Flowchart of Cost and Loss Analysis

the grower is trying to minimize his expected loss from a forthcoming weather event of uncertain severity; where the grower is risk averse, he may wish to control his downside loss, if possible. His decision concerns whether or not to protect by lighting heaters or starting wind machines, or both. But the decision comes in two stages, since early in the evening, around 7:00 p.m., the grower must decide upon bringing in a labor crew to staff the heaters and wind machines. The decision to "fire" comes later that night, any time from, say, 10:00 p.m. until almost dawn. The grower may, of course, enlist a labor crew without firing, but it is not really possible to fire without having hired workers earlier in the evening.

The decision itself may well be an expensive one, for better or worse. In the 1976-77 season, growers protected their groves during the January 19 freeze at an average cost (for those who did protect) of about \$50 per acre. The alternative, though, is to bear an increased risk of losing over \$1,000* per acre of fruit, not including tree damage.

Among the factors which affect the protection decision, the most important usually is the expected severity of the coming freeze. This information, combined with the expected market price for the fruit, provides a measure of the amount which could be lost if no protection is undertaken. Given the expected severity of the freeze (including its duration), the grower usually has a good idea of how much it will cost to protect. In some years (the 1976-77 season provided a possible example), the price of fruit may be so low, and/or the price of fuel so high, that the grower will fire only to protect his trees. (One grower interviewed in December 1976 indicated that he expected the price of oranges to be so low that he was not even going to bring out his heaters for this season.)

* For example, average 1975-76 yield for growers of white seedless grapefruit in the sample groves was 460 boxes per acre; 1975-76 "on-tree" average price for fresh grapefruit was \$2.56. This provided a per acre return of \$1177.5 per acre.

In comparing the control group results with the test group results, it is, of course, important to control for the various confounding variables. This is done by maintaining as many as possible of the same growers in the sample and by normalizing with respect to weather severity. However, one possible confound not fully accounted for is the effect of year-to-year changes in the expected price of fruit. Fruit supply conditions in 1976-77 were such that extremely low fruit prices were anticipated at harvest. Due to freeze damage to the trees, however, fruit production was expected to be relatively low in 1977-78, thus causing unusually high prices. These conditions caused concern since there existed the possibility that the protection decisions made by the growers might have changed fundamentally between the two control years. Interviews conducted with growers and extension agents in Florida, however, substantially allayed fears that this price change would be an important confound. Protection strategies were extensively discussed with four of the largest growers in ECON's sample. These growers described the "rules of thumb" used in making the protection decision: if the minimum temperature forecasted at 4:00 p.m. was below some threshold value (usually 24°F-26°F) protection crews were readied for the evening; heaters were lighted and wind machines started when the temperature fell below some temperature (24°F-27°F) and was not expected to start rising very soon. These practices are modified according to the timing of the freeze, the time of year, and the fruit type to be protected. The growers further indicated that these rules of thumb had not changed due to the higher prices anticipated. This was further confirmed in discussions with extension agents. Thus it is felt that the price change is not an important confound. When calculating the dollar value of per unit fruit losses (see Section 5.3.2), of course, a consistent value is to be used for both control and test groups.

5.2 Cost of Protection Modeling

Given the data provided in the Nightly Frost/Freeze Protection Reports (see Figures 3.4 and 3.5), the task of estimating the cost of protection each night, grove by grove, is very straightforward. Protection costs have three components: labor, fuel and "other" costs. Labor and "other" costs are identified directly by the grower on the Protection Report. Fuel costs are derived as follows:

$$C_F = \sum_{i=1}^{I_w} W_i * WFR_i * WFP_i + \sum_{i=1}^{I_h} H_i * HFR_i * HFP_i + (TM * TFR + AM * ARF) * PG$$

where W_i is the number of wind-machine-hours for the i^{th} type machine, WFR_i is the fuel consumption rate for the i^{th} type of machine and WFP_i is the price of fuel for the i^{th} type of machine. Correspondingly, H_i is the number of heater-hours for the i^{th} type of heater, etc. TM and AM are truck and automobile miles traveled, respectively, and TFR and AFR are truck and automobile fuel consumption rates. PG is the price of gasoline.

W_i , WFR_i , H_i , HFR_i , TM and AM are all obtained from the Nightly Frost/Freeze Protection Report. TFR and AFR estimates were obtained via the U.S. Department of Agriculture, from staff members working on energy consumption in agriculture. It was estimated that automobiles used on farms achieved 15 miles per gallon and trucks achieved 9.5 miles per gallon.* Fuel prices for the winter 1976-77 for the State of Florida were estimated from regional statistics provided by the state of Florida, State Energy Office.** The prices used in this study were:***

* Personal communication, Tom Van Arsdall, USDA, March 16, 1977.

** Personal communication, Tim Shey, Florida State Energy Office.

*** 1976-77 prices are used for the 1977-78 control year to maintain experiment control. These prices will also be used for the test group year.

<u>Fuel</u>	<u>Price/Gallon (Current Dollars)</u>
Gasoline	.583
Fuel Oil	.416
Diesel	.414
Propane	.429
Butane	.429

Total costs of protection, then, are computed as the sum of fuel, labor and "other" costs.

5.3 Fruit Loss Modeling

The most complicated task under the general analysis of costs and losses is the fruit loss modeling. The complication is due to the following factors:

- Economic losses in the marketplace are nonlinear.
- The amount of the economic loss sustained by any grower depends upon what has happened in the rest of the industry.
- The size of the physical loss from any weather event depends upon previous damage, and thus, previous weather.
- The loss depends upon what the grower had intended to do with the fruit before a freeze and what he was eventually able to do with it, possibly after a significant disruption to the market caused by a freeze.

The general approach to estimating the social value of fruit losses is depicted in Figure 5.2. Growers will market all the fruit they have available, so long as the price of the fruit exceeds the costs of pick and haul, that is, so long as "on-tree" prices exceed zero. ("On-tree" prices are reported by the Florida Crop and Livestock Reporting Service and are equal to the delivered-in price of fruit, less the estimated costs of pick and haul.) Typically, the reduction in industry supply of fruit due to a freeze (from S_1 to S_2 in Figure 5.2) moves prices upwards (P_1 to P_2). The total economic loss to society is the shaded area under the demand curve. This

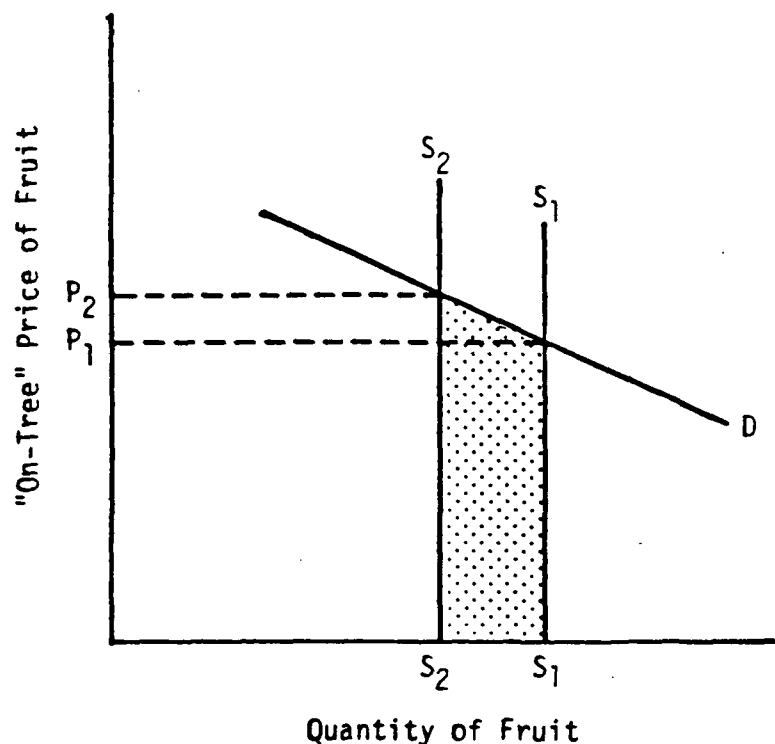


Figure 5.2 The Economic Value of Fruit Losses

loss can be prorated to each grower by dividing the total value loss (the shaded area) by the physical loss ($S_1 - S_2$) to obtain an economic loss per unit of physical loss. This process can be performed repetitively if there is more than one freeze during the season. The elements necessary to perform the operation shown in Figure 5.2 are (1) the supply "before," (2) the supply "after," and (3) the demand function.

This economic or "social" loss is to be distinguished from losses (or gains) to the grower in the form of reduced (or increased) revenues. In general, a reduction in the supply of citrus causes prices to increase sufficiently so that industry revenues increase in spite of physical losses. This phenomenon occurs when the market elasticity of demand is less (in absolute value) than one. Such is typically the case in agricultural commodities and is estimated to be the case with citrus, as is shown in the following section (see Table 5.1).

Table 5.1 Summary of Citrus Demand Modeling Results*

Market	Explanatory Variables								R ²	Demand Elasticity
	Constant	Supply	S ²	S ³	PDI	Yield	Trend	Cycle		
Early & Mid, Processed	7.357	-0.2896 (-3.217)	0.00379 (2.218)	-0.0000168 (-1.661)		0.927 (1.200)			.85	-0.5926
Early & Mid, Fresh	11.942	-0.5102 (-4.050)			-2.4151 (-5.822)			0.3164 (1.709)	.76	-0.4155
Valencias, Processed	13.114	-0.5581 (-2.849)	0.00897 (2.202)	-0.0000486 (-1.820)				0.1768 (1.362)	.91	-0.4331
Valencias, Fresh	14.331	-0.6222 (-6.381)			-3.328 (-8.364)			0.4900 (2.760)	.86	-0.4531
Grapefruit, Processed	-7.359	-0.0698 (-1.940)			5.1397 (2.179)		-0.3143 (-1.861)		.33	-0.1581
Grapefruit, Fresh	4.417	-0.1811 (-2.989)					0.0489 (2.167)	0.2885 (2.176)	.51	-0.4063
Temple, Fresh	7.348	-1.2809 (-4.200)					-0.1751 (-5.583)	0.2647 (1.240)	.81	-0.4976
Tangelos, Fresh	18.622	1.4180 (0.387)	-4.5363 (-1.512)	1.2488 (1.726)	-7.2164 (-2.254)		0.5596 (2.123)	0.5979 (3.715)	.97	-1.3732
Tangerines, Fresh	8.508	-1.1960 (-3.039)			-1.0294 (-2.501)			0.4376 (2.138)	.61	-0.9605

NOTES:

1. The dependent variable throughout is "on-tree" prices, expressed in constant 1967 dollars.
2. The numbers shown are least squares regression coefficients; the numbers in parentheses are t-values for the corresponding variables.
3. SUPPLY represents boxes of fruit sold, in millions
4. S² and S³ are the squared and cubed terms of SUPPLY.
5. PDI is real personal disposable income in 1967 constant dollars.
6. YIELD is expressed in gallons of concentrate per box.
7. Elasticity calculated from estimated demand curve slope and 1975-76 prices and quantities.

5.3.1 Modeling the Demand for Citrus Fruits

Estimates of the demand function were made using simple econometric models of the citrus markets. Separate demand function estimates were made for each fruit variety and according to whether the fruit is sold fresh or for processing. Fresh fruit typically fetches a higher price but its demand is much less elastic and is easily saturated in times of large supply. Fruit originally intended to be sold fresh may go to processors either because a relative surplus of fresh fruit has forced down the price or because of freeze or pest damage. Fruit originally intended for processing typically is not of a high enough grade to be sold for fresh, except in times of large freezes when the standards for fresh fruit leaving the state are sometimes lowered by the Florida Division of Fruit and Vegetable Inspection.

The demand functions depicted in Figure 5.2 are estimated according to the following model. The real price paid (the consumer price index was used as a deflator throughout) to the grower for fruit is considered to be a function primarily of the amount of fruit available. Additional explanatory variables hypothesized for fresh fruit demand were the price of some substitute (fresh apples were used) and real personal disposable income (PDI). For processed fruit, real personal disposable income and per box yield were also tested as explanatory variables. For some markets, a trend term was also used.

The annual time series used for the establishment of the demand functions were found in the annual Citrus Summary published by the Florida Crop and Livestock Reporting Service; in Commodities Yearbook published by The Commodity Research Bureau, Inc.; Business Conditions Digest published by the U.S. Department of Commerce; and in the Statistical Summary of the Florida Cannery Association.

Table 5.1 summarizes the results of the regression analyses. The demand equation for processed early and midseason oranges, for example, would be read from Table 5.1 as follows:

$$\begin{aligned} \text{Price Per Box (on-tree, 1976\$)} &= 7.357 - 0.2896 \times \text{supply (number of} \\ &\quad \text{boxes of processed fruit)} \\ &\quad + 0.00379 \times (\text{supply})^2 - 0.0000168 \times (\text{supply})^3 \\ &\quad 0.0 \times \text{personal disposable income (1967\$)} \\ &\quad + 0.927 \times \text{Yield Per Box (gallons of concentrate)} \\ &\quad + 0.0 \times (\text{Year} - 1959) + 0.0 \times \text{Cosine } ((\text{Year} - 1959) \times \pi/2). \end{aligned}$$

The results were approximately as expected. All the demand elasticities^{*} have the correct sign. The elasticity values are similar to the elasticities found by Myers for retail frozen concentrated orange juice demand: -0.546^{**} (which compares favorably with the estimated -0.5926 for processed early and midseason oranges). The specialty fruits, tangelos and tangerines, were an exception and showed themselves to possess more elastic demands. This was somewhat surprising, but is probably due to their very small market share. The price of the substitute for fresh citrus (apples) was not significant in any of the regressions.

Surprisingly, income elasticity of demand for fresh citrus was estimated to be less than zero. Although it is possible that this could simply be a trend effect of diminishing fresh citrus demand over the years 1960-1976, when real PDI was increasing, the negative coefficient on PDI remained even when a trend term was tested in the regression. The only exception to this was when PDI was tested in the

^{*} Demand elasticities are measures of the sensitivity of quantity demanded as price changes. They are calculated as $E = \frac{\partial p}{\partial q} \cdot \frac{q}{p}$, where p is price and q is quantity.

^{**} L. H. Myers, The Consumer Demand for Orange Beverages, Economic Research Department, Report No. FCC-ERD-69-1, University of Florida, August 1969.

demand for processed grapefruit. Here the sign was positive, but the regression as a whole was not significant.

Two other surprises were evident. First, only in the price of processed early and mid-season oranges did the yield per box become a significant explanatory variable. Secondly, a four-year cycle was found in the regression residuals for many of the markets (all except processed early and mid and processed grapefruit). When included in the regression, this cycle term usually proved quite significant and relatively strong. The presence of this effect is not fully understood; however, it is possible that it refers to the length of recovery periods after severe and extensive freezes.

5.3.2 Estimating Industry Fruit Losses

Estimates of supplies before and after freezes are made using Florida Crop and Livestock Reporting Service (FCLRS) Citrus Forecasts and their updates. In December 1976, prior to the severe freeze in January, the FCLRS made a forecast of citrus production for the 1976-77 season. This forecast had been updated several times since and a "final" production estimate for the 1976-77 crop season was released October 6. Table 5.2 summarizes these forecasts and estimates. The later estimates take into account damage suffered from the January freeze and it is felt^{*} that the best way to estimate the amount of that damage is a simple subtraction of later production estimates from the December estimate (i.e., the last one prior to the freeze). Utilization forecasts are not provided by FCLRS and average percentages utilized for fresh and processed for the last three years were used for the before-freeze estimates of utilization.

—^{*} Personal communication, Paul Messinger, FCLRS, March 28, 1977.

Table 5.2 Citrus Industry Physical Fruit Losses and Economic Losses** (1976-77)									
Utilization of Citrus Crop (Millions of Boxes)									
Fruit Variety	Fresh			Processed			Physical Loss		
	Before	After	Physical Loss	Before	After	Physical Loss	Before	After	Physical Loss
Early & Mid	8.37	6.13	2.24	112.65	108.87	3.78			
Valencias	6.16	2.75	3.41	81.84	69.05	12.79			
Grapefruit	23.69	16.39	7.30	34.31	35.11	-0.80			
Temples	2.18	1.18	1.00	3.52	2.62	0.90			
Tangelos	2.46	2.30	0.16	3.04	2.51	0.53			
Tangerines	4.14	2.32	1.82	1.66	0.98	0.68			
Estimated Citrus Industry Economic Loss (Millions of 1976 \$)**									
	Fresh			Processed			Total		
	Revenue Gain	Societal Loss	Societal Loss Per Box Lost (\$ Per Box)	Revenue Gain	Societal Loss	Societal Loss Per Box Lost (\$ Per Box)	Revenue Gain	Societal Loss	Societal Loss
Early & Mid	6.99	3.24	1.45	2.61	2.95	0.78	9.6	6.19	
Valencias	2.21	9.38	2.75	33.24	23.41	1.83	35.45	32.79	
Grapefruit	7.77	17.08	2.34	-2.61	-0.52	0.65	5.16	16.56	
Temples	-1.93	2.60	2.60	-0.41	-0.41	0.45	-2.34	3.01	
Tangelos	-0.08	0.32	7.00	*	*	*	-0.08	2.00	
Tangerines	8.40	5.31	7.92	*	*	*	-8.40	2.92	
TOTALS:							39.39	63.47	
* Insufficient information, but appears to be near zero									
** Source: Florida Crop and Livestock Reporting Service.									

Losses in 1977-78 (at least for the experiment sample) were negligible and were not quantified.

5.3.3 Estimating Economic Value of Fruit Losses

Using the results of Sections 5.2.1 and 5.2.2, the social costs and revenue gains to the Florida citrus industry of the 1976-77 freezes (of which the January freeze dominated) were calculated. The first step in these calculations is the estimation of before- and after-freeze prices. After-freeze prices were estimated by the FCLRS in its October 6, 1977 report. Before-freeze prices are estimated by using the before-freeze production estimates shown in Table 5.2, the demand curve estimates of Table 5.1, and adjusting upwards from 1967 to 1976 dollars. In three instances (early and mid processed, grapefruit processed, and tangelos fresh), this procedure yielded unsatisfactory results when compared to what prices seemed to be forthcoming at the beginning of the season. This indicates that the demand curve for these products had shifted for the 1976-77 season when compared to the curve statistically estimated from 1960-1976 demand data. In these cases, a linear demand curve, with the elasticity estimated and shown in Table 5.1, was assumed passing through the season's-end price-quantity point as reported by the FCLRS. The results of these calculations, before- and after-freeze, on-tree prices, are reported in Table 5.3.

Some comment on the prices in Table 5.3 is in order. In general, 1976-77 was to be a record crop year. Even after sizable losses, in fact, several crops were produced at record quantities. The pattern which was found, then, is one of very low estimated, before-freeze prices. This is attributable not only to the record harvests which were forecast, but also to the inelastic demand for most citrus products: the existing demand is quickly saturated. Thus, some dramatic price reversals are predicted based on losses from the January freeze. Fresh tangerines,

Table 5.3 Estimated 1976-77 Before-Freeze and After-Freeze
On-Tree Citrus Prices* (1976 \$ Per Box)

Fruit Variety	Fresh		Processed	
	Before	After	Before	After
Early & Mid.	0.75	2.15	0.75	0.80
Valencias	1.45	4.05	1.45	2.20
Grapefruit	1.72	2.96	0.69	0.60
Temples	2.40	2.80	**	0.45
Tangelos	1.95	2.05	**	-0.35
Tangerines	0.80	5.05	**	-0.85

* After-freeze prices estimated by FCLRS; before-freeze prices estimated by ECON.

** Insufficient data for estimation.

for example, went from an estimated before-freeze price of \$0.80 per box to an average grower return (on-tree price) of \$5.04 per box after the industry lost nearly 44 percent of the crop. Tangelos, however, escaped relatively unscathed, losing less than 7 percent of the fresh crop, while prices increased only \$0.10. In general, however, the fresh fruit left after the freeze fetched a considerably higher price than it would have without the freeze and growers in the control group sample as well as the industry benefited considerably in higher revenues.

The negative after-freeze "prices" for processed tangelos and tangerines refer, of course, to losses (costs exceeding revenues) in the production of these commodities. Negative on-tree prices for processed specialty fruit are not terribly

uncommon. The abundance of freeze-damaged fruit intended for fresh but ultimately going processed aggravated an already weak market.

Using these estimated prices, industry's revenue gains and social losses attributable to the freeze were estimated. These figures are also presented in Table 5.2. Further, in order to facilitate the estimation of social losses from the sample groves, social-loss-per box lost figures were estimated and are also shown in Table 5.2.

The bottom line of this analysis is that growers in the Florida citrus industry benefited substantially from the January 1977 freeze; revenues for the crops investigated increased more than \$39 million. This gain derived solely from increased prices and was therefore entirely at the expense of the citrus consumer. The revenue gain has no overall social benefit impact as it is simply a transfer payment with society none the worse off from it, per se. The physical loss of the crop, however, did translate into a societal, economic loss, estimated at over \$63 million.

Due to the very small amount of losses, the calculations were not performed for 1977-78.

5.4 Tree Loss Modeling

An input to the analysis is a vector of lost production in future years attributable to tree damage on a night-by-night, grove-by-grove basis. This information is derived from data obtained in the Damage Reports (see Figures 3.7 and 3.8). The costs associated with cultural activities (pruning dead twigs, etc.) necessitated by tree damage were not estimated in this study.

The model used is a simple one. The objective is to obtain the present value of the foregone citrus production. Given the vector of future production losses, $L = (L_1, L_2, L_3, \dots, L_T)$, this present value is expressed as

$$PV = \sum_{t=1}^T \frac{\hat{P}_t}{(1+d)^t} L_t$$

where T is the number of years until full production, $\hat{P}_t$ is forecasted price for the particular citrus variety t years from the present, and d is the annual discount rate. A discount rate of 7.5 percent is used in this study.

The above equation implicitly assumes that industry tree losses are sufficiently small so as not to affect $\hat{P}_t$. Although this is a questionable assumption, the only alternative is to estimate the vector in future industry reductions in production attributable to particular freezes, a task which is far beyond the scope of this study. The use of the above equation leads to a small bias in favor of underestimating the economic losses.

Toward the estimation of $\hat{P}_t$ in the above equation, much analysis could be performed. However, unless a very large task was undertaken, the resulting forecasts would not likely be any more accurate than using current year prices. As a consequence, 1975-76 prices were used as forecasts of future prices, $\hat{P}_t$.

5.5 Costs and Losses for the Sample Groves: Results

This section summarizes, in tabular form, the economic costs and losses attributable to freezes and freeze protection during 1976-77 and costs for 1977-78 for the control group citrus groves. Due to an inability to obtain sufficient information with which to make estimates of losses from tree damage, no tree losses are reported.

Tables 5.4 and 5.5 summarize reported total and per acre costs of protection for the sample by county and fruit type for 1976-77. Tables 5.6 and 5.7 show the same for 1977-78. Total and per acre revenue gains and social losses are presented in Tables 5.8 through 5.11. The results largely speak for themselves. The total

Table 5.4 Reported Total Costs of Protection (Thousands of Dollars) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By County and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	4.0	9.5	0.3	14.3	29.5	5.4	63.0
Polk	50.1	100.2	13.1	1.0	37.4	5.1	206.9
Orange	22.1	27.1	30.8	*	1.3	0.2	81.5
Lake	20.4	33.5	8.3	6.2	1.2	4.1	73.7
Marion	6.1	0	*	*	0	0	6.1
Osceola	8.5	2.1	*	*	0.8	2.2	13.6
Highlands	2.4	0.7	11.0	*	*	*	14.1
Hardee	7.2	2.0	0	5.1	0	*	14.3
All Counties	120.8	175.1	63.5	26.6	70.2	17.0	473.2
*The sample contains no groves with this fruit variety in this county.							

Table 5.5 Reported Per Acre Costs of Protection (Dollars Per Acre) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By Country and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	16	102	150	146	280	150	109
Polk	76	95	110	75	168	49	95
Orange	50	148	103	*	22	10	81
Lake	59	25	56	72	7	43	33
Marion	48	0	*	*	0	0	32
Osceola	95	15	*	*	35	2	39
Highlands	29	13	92	*	*	*	54
Hardee	73	46	0	146	0	*	73
* The sample contains no groves with this fruit variety in this county.							

Table 5.6 Reported Total Costs of Protection (Thousands of Dollars) Attributable to Impact of Frosts and Freezes for 1977-78 Crop Year--For Entire Sample--By County and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	8.5	0.0	*	0.3	2.1	0.0	10.9
Polk	6.1	16.4	7.0	0.0	3.9	2.4	35.8
Orange	11.2	6.1	6.1	*	*	0.0	23.4
Lake	12.1	20.1	1.3	1.0	2.2	0.6	29.1
Marion	4.0	4.1	*	*	0.2	0.6	8.9
Osceola	0.0	2.9	*	*	2.4	10.6	16.0
Highlands	0.5	0.9	*	*	0.3	*	1.8
Hardee	0.0	1.4	0.0	0.0	0.3	*	1.7
All Counties	42.5	43.9	14.4	1.3	11.4	14.3	127.6
* The sample contains no groves with this fruit variety in this county.							

Table 5.7 Reported Per Acre Costs of Protection (Dollars Per Acre) Attributable to Impact of Frosts and Freezes for 1977-78 Crop Year--For Entire Sample--By Country and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	40	0	*	4	33	0	24
Polk	9	22	88	3	32	48	21
Orange	26	45	32	*	*	0	30
Lake	34	9	8	11	18	10	14
Marion	32	90	*	*	18	118	47
Osceola	0	21	*	*	108	106	46
Highlands	19	22	*	*	46	*	23
Hardee	0	32	0	0	36	*	9
*The sample contains no groves with this fruit variety in this county.							

Table 5.8 Estimated Total Revenue Gains (Thousands of Dollars) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By County and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	56.7	46.2	0.2	2.5	137.7	4.3	247.6
Polk	81.3	163.5	-50.3	0.8	11.2	7.9	214.4
Orange	233.0	9.4	-66.5	*	89.2	-11.1	254.0
Lake	1.6	288.5	0.8	3.9	31.2	5.1	331.1
Marion	8.6	11.1	*	*	10.6	-0.2	30.1
Osceola	-0.1	47.8	*	*	25.8	74.5	148.0
Highlands	-0.5	28.0	-115.3	*	*	*	-87.8
Hardee	0.7	20.7	2.0	-9.8	17.0	*	30.6
All Counties	381.3	615.2	-229.1	-2.6	322.7	80.5	1168.0
*The sample contains no groves with this fruit variety in this county.							

Table 5.9 Estimated Per Acre Revenue Gains (Dollars Per Acre) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By County and Fruit Variety								
County	Fruit Variety							
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties	
Hillsborough	232	495	100	26	1,306	119	428	
Polk	124	155	-422	60	50	76	98	
Orange	523	51	-222	*	1,487	-566	250	
Lake	5	212	5	23	185	53	147	
Marion	67	247	*	*	1,060	-40	160	
Osceola	-1	348	*	*	1,137	745	423	
Highlands	6	532	-961	*	*	*	-335	
Hardee	7	476	200	-280	1,889	*	156	
*The sample contains no groves with this fruit variety in this county.								

Table 5.10 Estimated Total Social Value of Fruit Loss (Thousands of Dollars) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By County and Fruit Variety							
County	Fruit Variety						
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	All Varieties
Hillsborough	0	8.4	0	0	21.6	0	30.0
Polk	173.2	312.0	66.5	0	121.2	8.7	681.6
Orange	46.6	51.0	103.8	*	0	18.8	220.2
Lake	23.9	141.6	13.1	0	53.7	0	232.3
Marion	7.4	1.3	*	*	0	0.1	8.8
Osceola	15.0	5.0	*	*	2.0	0	22.0
Highlands	10.7	5.1	126.3	*	*	*	142.1
Hardee	0.5	0	0	10.6	0	*	11.1
All Counties	277.3	524.4	309.7	10.6	198.5	27.6	1,348.1
*The sample contains no groves with this fruit variety in this county.							

Table 5.11 Estimated Per Acre Social Value of Fruit Loss (Dollars Per Acre) Attributable to Impact of Frosts and Freezes for 1976-77 Crop Year--For Entire Sample--By County and Fruit Variety							
County	Fruit Variety						All Varieties
	Early & Mid Oranges	Valencia (Late) Oranges	Temple	Tangelos	Tangerines	Grapefruit (All Types)	
Hillsborough	0	90	0	0	205	0	52
Polk	264	296	558	0	545	84	311
Orange	105	278	347	*	0	959	216
Lake	69	104	88	0	318	0	103
Marion	58	29	*	*	0	20	47
Osceola	168	36	*	*	88	0	63
Highlands	131	97	1,053	*	*	*	543
Hardee	5	0	0	303	0	*	57
* The sample contains no groves with this fruit variety in this county.							

social cost of the freeze and frosts would be calculated by summing protection costs with the social loss figures of Tables 5.10 and 5.11. The net impact of the freeze and frosts upon growers in the sample is calculated by subtracting protection costs from revenue gains, then obtaining net revenue gains. In summary, the severity of the 1976-77 crop year benefited the growers in the control group sample by \$695,000. The total social cost of the weather year to the control group was \$1,821,000. Consumers of Florida citrus products fared even worse, as they bore the brunt of the \$1.8 million social cost and, additionally, provided all the growers net benefit in the form of a transfer payment.

5.6 Expansion of Costs and Losses*

In order to expand the control group sample results to the state of Florida, it is necessary to develop expansion or scaling factors which relate the sample to the industry. The costs and losses are to be expanded only to the protected acreage within the state of Florida. The total protected acreage within the state is not known with a high level of accuracy. In order to estimate the protected acreage, the county extension agents were asked for their estimate of the protected acreage by fruit type, in their respective counties. The agents were able to estimate aggregate protected acres for the county but were unable to break down the acreage by fruit type. The estimates of protected acreage are shown in Table 5.12. Also shown in Table 5.12 are the results of a survey of heater inventory made several years ago by the Florida Citrus Mutual. This survey was made prior to the drastic increase in the price of fuel, which may explain some of the discrepancies (many heaters were retired).

* These calculations were not done for the 1977-78 year.

Table 5.12 Protected Acreage			
County	Estimates *	Protected Acreage*	Florida Citrus Mutual Survey (Heaters)
Marion	60% of 11,327	6,796	7,134
Lake/Orange	15% of 180,023	27,003	8,350
Hillsborough	~5% of 39,750	1,988	23,293
Hardee	5% of 44,812	2,241	3,042
Polk	15,000 acres	15,000	30,000
Highlands	7,000 acres	7,000	6,200
* Estimated by county extension agents.			

In the absence of detailed data it was decided to assume that the ratio of protected acreage of a particular fruit type to the total acreage of that fruit type equals the ratio of the county total protected acreage to the county total acreage.

$$\frac{\text{County Total Protected Acreage}}{\text{County Total Acreage}} = \frac{\text{Protected Acreage for Fruit Type}}{\text{Total Acreage for that Fruit Type}}$$

This assumption was for early and midseason oranges and valencias. The county total acreage, and the acreage in each county by fruit type was obtained from the 1976 Citrus Summary prepared by the Florida Crop and Livestock Reporting Service. It was assumed that 90 percent of the specialty fruit was protected acreage, and that 10 percent of the grapefruit was protected. Using these assumptions, it was possible to estimate the protected acreage by fruit type and by county as indicated in Table 5.13. The data presented in Table 5.13 also includes adjustments to the county extension agents' estimates to take into account the fact that in several instances, the sample groves contained more protected acreage than was estimated for the county as a whole.

Table 5.13 Estimated Protected Acreage By County And Fruit Type (1976)

County	Early And Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	5,058	6,134	2,459	8,694	22,745
Orange	3,980	2,988	241	6,760	13,969
Lake	8,221	7,065	2,683	1,710	19,679
Marion	5,282	826	40	590	6,738
Hillsborough	1,013	645	254	2,979	4,891
Osceola	1,177	915	125	1,560	3,777
Highlands	1,407	3,767	452	3,933	9,559
Hardee	1,230	781	90	2,125	4,226
Total	27,368	23,121	6,744	28,351	85,584

It was not possible to make these same assumptions for the production (yield) of citrus in order to expand the sample data. This is because the yield for protected acres differs from the yield for unprotected acres. Therefore, in order to estimate the production by county and fruit type, it was necessary to assume that the yield per acre for the control group sample is the same as the average yield per acre for protected acres. Table 5.14 lists the yield per acre for the sample by county and fruit type. The eight counties represented in the control group sample accounted for approximately 55 percent of the total citrus acreage, and 60 percent of the total citrus production for the state of Florida in 1976.

By dividing the control group sample acreage by the estimated protected acreage (for each county and fruit type), the percentage is obtained (by county and by fruit type), that is represented by the sample (see Table 5.15). The total costs and losses (by county and by fruit type) are obtained by dividing the sample results (by county and by fruit type), by these percentages. In cases where the percent represented equals zero, it is not possible to expand. By summing these quotients,

Table 5.14 Control Group Sample Average Yield Per Acre For The 1975-76 Crop Season, In Boxes, By County And Variety Of Citrus

County	Early And Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	421.5	344.9	437.4	390.1	384.2
Orange	420.4	333.9	545.0	334.5	373.6
Lake	429.9	396.2	393.0	345.1	392.6
Marion	400.2	298.3	180.0	280.0	354.1
Hillsborough	361.8	323.7	69.0	248.2	284.7
Osceola	293.0	436.5	600.0	209.5	372.3
Highlands	517.3	508.5	0.0	389.5	478.3
Hardee	288.3	451.7	0.0	427.0	389.0

Table 5.15 Percentage Of Total Protected Acreage Represented By The Control Group Sample

County	Early And Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	13.0	17.2	4.2	4.3	9.8
Orange	11.2	6.1	8.3	5.5	7.3
Lake	4.2	19.3	8.0	26.6	12.2
Marion	2.4	5.5	12.5	16.9	2.8
Hillsborough	24.1	14.4	14.2	6.9	11.8
Osceola	7.6	15.1	80.0	1.5	9.3
Highlands	5.8	1.4	0.0	3.2	2.7
Hardee	8.0	5.6	0.0	2.5	4.6
Total					8.4

the total costs and total losses are obtained for the eight counties represented by the control group sample. The results are summarized in Tables 5.16* to 5.18.

5.7 Statistical Analysis of Relationship Between Costs and Losses and Weather Severity

So far, Section 5 has been concerned with the cost and loss estimation methodology and results from the control group sample for the 1976-77 and 1977-78 seasons. Additionally, these results have been expanded or extrapolated to the entire Florida citrus industry. However, the costs and losses presented herein so far are very much dependent upon the particular weather experienced during the particular crop seasons studied. Any attempt to relate these costs and losses to those from other years (when a different weather forecasting system may be in effect), will be tremendously confounded unless the differences in weather are accounted for.

* It should be noted that it is tempting to multiply the protection costs as given in Figure 1.11 by the total protected acreage. This will lead to erroneous results as can be seen from the following two methods of computing protection cost for a single frost night.

$$1. \quad \text{Protection Cost} = \bar{C} * \sum_{M,N} A_{M,N}$$

$$\bar{C} = \frac{\sum_{M,N,G} A'_{M,N,G} * C'_{M,N,G}}{\sum_{M,N,G} A'_{M,N,G}}$$

$$2. \quad \text{Protection Cost} = \sum_{M,N} \bar{C}_{M,N} * A_{M,N}$$

$$\bar{C}_{M,N} = \frac{\sum_G A'_{M,N,G} * C'_{M,N,G}}{\sum_G A'_{M,N,G}}$$

where A = acreage, M = county, N = fruit type, G = grove, and primed terms refer to measured sample data. Also, $A_{M,N} = TA_{M,N} * CP_M / CT_M$ where TA = total Florida citrus acreage, CP = total county protected acreage and CT = total county citrus acreage. It can be seen that only under very special circumstances will methods (1) and (2) provide the same results. Method 2 yields more accurate results.

Table 5.16 Total Cost of Protection by County and Fruit Type, 1976-77 Crop Year (\$, Thousands)

County	Early & Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	385	583	121	1198	2287
Orange	197	444	2	584	1228
Lake	486	174	51	59	770
Marion	254	0	0	0	254
Hillsborough	17	66	38	639	760
Osceola	112	14	3	53	182
Highlands	41	50	*	344	435
Hardee	90	36	*	204	330
Total	1582	1366	216	3081	6244

* Indicates no sample points in database.

Table 5.17 Grower Revenue Change by County and Fruit Type, 1976-77 Crop Year (\$, Thousands)

County	Early & Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	625	951	188	-891	873
Orange	2080	154	-134	413	2513
Lake	38	1495	64	135	1732
Marion	358	202	-2	63	621
Hillsborough	235	321	30	2035	2621
Osceola	-1	317	93	1720	2128
Highlands	-9	2000	*	-3603	-1612
Hardee	9	370	*	368	746
Total	3336	5808	240	239	9624

* Indicates no sample points in database.

Table 5.18 Social Loss by County and Fruit Type, 1976-77 Crop Year (\$, Thousands)					
County	Early & Midseason	Valencia	Grapefruit	Specialty Fruit	Total
Polk	1332	1814	207	4365	7719
Orange	416	836	227	1887	3366
Lake	569	734	0	251	1554
Marion	308	24	1	0	333
Hillsborough	0	58	0	313	371
Osceola	197	33	0	133	364
Highlands	184	364	*	3947	4496
Hardee	6	0	*	424	430
Total	3014	3863	435	11321	18632
*Indicates no sample points in database.					

Thus, ECON undertook the effort of disassociating the costs and losses from the particular weather pattern of 1976-77 and for that of the second control years, 1977-78. Referring back to Figure 5.1, the steps leading to the "description of economic costs and losses by grove and weather event" have already been performed and reported, while the statistical analysis of the relationship between costs, losses and weather severity, and predictions for historical weather years, are yet to be discussed.

The objective of the statistical analysis was to establish an explicit relationship between costs and losses and weather severity. Once this relationship was enumerated, weather years other than 1976-77 or 1977-78 could be "played" through it to simulate what costs and losses would have been for different weather years. Thus, some statistics could be generated (say, average annual costs and losses for weather years represented by weather data 1959-1969) which are

independent of the particular weather pattern in effect when the data were gathered.

The statistical analysis employed to establish the explicit relationship between costs and losses and weather severity started with a model of the following form:

$$C_i = \alpha + \beta S_i + \gamma T_i + \delta F_i \quad (5.1a)$$

$$L_i = \epsilon + \zeta S_i + \eta T_i + \theta F_i + K C_i. \quad (5.1b)$$

The above model is referred to as the linear form. An alternative form is:

$$C_i = \alpha S_i^\beta T_i^\gamma F_i^\delta \quad (5.2a)$$

$$L_i = \epsilon S_i^\zeta T_i^\eta F_i^\theta C_i^K. \quad (5.2b)$$

This model is referred to as the log form. The variables are defined for each observation, i (where each white form for each grove represents an observation), as:

C_i = costs of protection per acre

S_i = weather severity

T_i = time of year (number of days from November 1)

F_i = annual FCIC insurance premium per acre

L_i = net revenue loss per acre, constant at 1975-76 averages assumed.

Costs of protection, then, are assumed to be a function of the weather severity, the crop susceptibility (represented by the time of year) and the grove susceptibility (represented by the premium). Losses are a function of the same parameters and the amount of protection employed as measured by the costs of protection. The sample is stratified in various ways and the equations above

pertain to each subsample. The most important stratification is by fruit variety such that a model is estimated for each variety.

The normalization was not carried out completely during the first year, however, because of insufficient time to develop statistically significant results. It should be noted that the statistical analysis could not be initiated until all loss data was received from the growers. This data was not forthcoming until October (plans were to receive all data shortly after the last harvest--July). Even when only those observations with positive costs were considered, the cost regressions were very weak. For example, the best regression for costs of protection of valencias in the northern counties yielded an R^2 of only 0.05 (that is, only 5 percent of the variation in cost was explained by our model). Similar results were obtained for costs with the other fruit varieties. The percentage variation explained improved for the loss equations: 31 percent for early and mids, 72 percent for valencias, 43 percent for specialty fruit, and back down to 5 percent for grapefruit. Although these are considerably improved, they still do not produce the kind of estimates with which it is comfortable to work.

Since there exists a trade-off between costs and losses, a variable representing their sum was also tested. These cost-plus-loss regressions yielded somewhat better results. Table 5.19 presents a partial listing of the regression results found. In general, the regressions not shown here yielded somewhat poorer results.

Due to the low significance of these regressions, further statistical exploration of the 1976-77 data was conducted during the second project year. Many possible relationships were tested, particularly between the cost/loss variables and measures of the weather. It was discovered that, while the severity measure developed was the best predictor of losses, it was not a good predictor of costs.

Table 5.19 Estimated Statistical Relationships Between
Costs and Losses and Weather Severity

Fruit Variety	Dependent Variable	Model	Explanatory Variables				R ²
			Constant	Severity	(Severity) ²	Time	
Early and Midseason	Loss, Northern Counties	Linear	44.85	3.73 (4.25)			0.31
	Cost + Loss, Northern Counties	Linear	6.06	6.09 (10.98)	-0.012 (0.83)	-0.051 (0.46)	0.53
	Loss, Southern Counties	Linear	125.5	6.13 (3.07)			0.22
	Cost + Loss, Southern Counties	Linear	19.87	11.77 (5.45)	-0.022 (0.26)	-0.141 (0.58)	0.43
Valencia	Loss, Northern Counties	Linear	31.9	4.25 (10.63)			0.72
	Cost + Loss, Northern Counties	Linear	1.59	4.41 (8.05)	-0.006 (0.50)	0.007 (0.07)	0.55
	Loss, Southern Counties	Log	3.88	0.507 (2.90)			0.13
	Cost + Loss, Southern Counties	Linear	13.65	22.79 (7.17)	-0.382 (3.12)	-0.235 (0.47)	0.28
Specialty Fruits	Loss, Northern Counties	Log	3.63	0.55 (4.22)			0.42
	Cost + Loss, Northern Counties	Linear	-10.39	11.95 (8.93)	-0.104 (4.10)	0.120 (0.42)	0.40
	Cost + Loss, Southern Counties	Linear	121.54	14.39 (3.07)	-0.096 (0.73)	-1.08 (1.06)	0.15
Grapefruit	Cost + Loss Northern Counties	Linear	33.81	-35.47 (7.43)	2.83 (13.04)	-0.073 (0.27)	0.90
	Loss, Southern Counties	Log	8.6	-1.37 (1.08)			0.23
	Cost + Loss Southern Counties	Linear	-11.02	104.19 (3.29)	-6.15 (2.05)	0.073 (0.04)	0.22

- Notes: 1. The numbers shown are regression coefficients; the numbers in parenthesis are the t - values.
2. Losses calculated as physical losses multiplied by average 1975-76 prices.
3. ECON's fruit severity index used as measure of weather severity; see Section 3.
4. Losses are regressed only on those observations where positive losses are indicated; costs + losses are regressed on all observations where white form existed in data base.

The minimum temperature forecast and hours under 28°F were found to be the best predictors of costs. Further, it was acknowledged that the protection decision was two-part in nature, with the laborers having to be called in first if there was to be an opportunity to take preventive action. Thus, the labor and nonlabor components were separated in the protection cost and estimated separately, with the former being used to predict the latter. It was also noticed that different groves responded differently for a given weather event and that this phenomenon contributed to the poor results of the regressions. Thus, dummy variables were used so as to shift the intercept term for each grove. All of these measures contributed to some improvement in the cost regressions, as shown in Table 5.20. In general, the regressions were significant and the estimated coefficients showed the correct sign. Some of the dummy variables proved to be very significant, but most did not. Other approaches such as stratifying the groves by protection technology type and adding grove size as an explanatory variable had negligible impact on the regressions.

The loss regressions were improved slightly by adding nonlabor costs (mostly fuel costs) as an explanatory variable, although the coefficients were surprisingly insignificant. The results are shown in Table 5.21.

Costs for the 1977-78 year were also estimated using the methods discussed above. These results are reported in Table 5.22 and there is little to add except to note that the regressions were not as good as those for 1976-77.

5.8 Normalization of Costs and Losses

It is anticipated that normalization of the costs and losses will be carried out when it is needed. Two points should be made here, though. First, the two control years should be aggregated to form a single, representative control year. This would be done simply by adding the observation of the second year to the first

Table 5.20 Final-Form Cost Regressions for 1976-77

FRUIT VARIETY	DEPENDENT VARIABLE*	COEFFICIENTS (AND T-STATISTICS) OF EXPLANATORY VARIABLES*				R ²
		CONSTANT	ln(LABOR+1)	ln(DOR28+1)	MINFOR	
VALENCIA	ln(LABOR+1)** NORTHERN COUNTIES	0.846		0.062 (2.87)	-0.031 (-5.79)	0.22
	ln(NONLAB+1)** NORTHERN COUNTIES	1.759	1.508 (12.65)	0.120 (2.36)	-0.067 (-5.23)	0.53
	ln(LABOR+1)** SOUTHERN COUNTIES	2.891		-0.000 (-0.000)	-0.160 (-11.10)	0.35
	ln(NONLAB+1)** SOUTHERN COUNTIES	1.814	1.376 (21.45)	0.050 (1.08)	-0.073 (-5.22)	0.73
	ln(LABOR+1) NORTHERN	0.831		0.081 (3.41)	-0.027 (-5.05)	0.35
	ln(NONLAB+1) NORTHERN	2.059	1.576 (12.21)	0.060 (1.03)	-0.075 (-5.59)	0.57
	ln(LABOR+1) SOUTHERN	2.563		0.067 (1.72)	-0.093 (-9.76)	0.53
	ln(NONLAB+1) SOUTHERN	1.943	1.498 (20.13)	-0.010 (-0.19)	-0.072 (-4.99)	0.78
EARLY & MID	ln(LABOR+1) NORTHERN	1.048		0.146 (5.60)	-0.042 (-6.93)	0.40
	ln(NONLAB+1) NORTHERN	2.278	1.578 (16.68)	-0.127 (-2.35)	-0.085 (-6.59)	0.61
	ln(LABOR+1) SOUTHERN	2.618		0.124 (2.54)	-0.80 (-7.29)	0.54
	ln(NONLAB+1) SOUTHERN	2.962	0.963 (9.89)	-0.036 (0.45)	-0.109 (-5.52)	0.60
GRAPEFRUIT	ln(LABOR+1) NORTHERN	0.330		0.117 (3.03)	-0.016 (-1.87)	0.37
	ln(NONLAB+1) NORTHERN	0.877	2.643 (8.63)	0.097 (0.94)	(-0.036) (-1.67)	0.69
	ln(LABOR+1) SOUTHERN	1.532		0.194 (2.33)	-0.059 (2.84)	0.49
	ln(NONLAB+1) SOUTHERN	1.964	1.310 (8.85)	0.185 (1.73)	-0.072 (-2.14)	0.84
SPECIALTY FRUIT	ln(LABOR+1) NORTHERN	0.975		0.136 (4.05)	-0.043 (-5.48)	0.40
	ln(NONLAB+1) NORTHERN	2.526	1.191 (10.80)	0.161 (2.43)	-0.094 (-6.06)	0.61
	ln(LABOR+1) SOUTHERN	3.013		0.188 (3.16)	-0.111 (-7.72)	0.63
	ln(NONLAB+1) SOUTHERN	3.907	0.453 (3.89)	0.385 (3.53)	-0.144 (-4.98)	0.59
*VARIABLES USED: LABOR - PER ACRE LABOR COSTS NONLAB - PER ACRE NONLABOR COSTS DOR28 - TIME IN HOURS THAT THE TEMPERATURE WAS BELOW 28° MINFOR - MINIMUM TEMPERATURE FORECAST ln(x) REPRESENTS THE NATURAL LOG OF x **THE FIRST SET OF EQUATIONS FOR VALENCIAS DO NOT USE DUMMY VARIABLES.						

Table 5.21 Final-Form Loss Regressions for 1976-77

FRUIT VARIETY	DEPENDENT VARIABLE*	COEFFICIENTS (AND T-STATISTICS) OF EXPLANATORY VARIABLES*			R ²
		CONSTANT	NONLAB	FSEU	
VALENCIA	LOSSPA NORTHERN COUNTIES	31.370 31.370	0.133 (0.53)	4.216 (10.31)	0.72
	LOSSPA SOUTHERN COUNTIES	162.696	-0.060 (-0.91)	5.687 (2.42)	0.11
EARLY & MID	LOSSPA NORTHERN	44.757	0.014 (0.05)	3.719 (4.01)	0.31
	LOSSPA SOUTHERN	103.135	0.395 (1.35)	6.803 (3.35)	0.26
GRAPEFRUIT	INSUFFICIENT DATA				
SPECIALTY FRUIT	LOSSPA NORTHERN	73.826	0.893 (2.00)	5.303 (2.97)	0.42
	LOSSPA SOUTHERN	694.393	-0.198 (0.28)	-4.761 (0.63)	0.03
* VARIABLES USED: LOSSPA - DOLLAR VALUE OF PER ACRE FRUIT LOSS NONLAB - PER ACRE NONLABOR COSTS FSEU - WEATHER SEVERITY INDEX					

Table 5.22 Final-Form Cost Regressions for 1977-78

FRUIT VARIETY	DEPENDENT VARIABLE*	COEFFICIENTS (AND T-STATISTICS) OF EXPLANATORY VARIABLES*				R ²
		CONSTANT	ln(LABOR+1)	ln(DUR28+1)	MINFOR	
VALENCIA	ln(LABOR+1) NORTHERN COUNTIES	0.581		0.372 (5.56)	-0.001 (-0.07)	0.45
	ln(NONLAB+1) NORTHERN COUNTIES	-0.001	0.066 (5.56)	-0.011 (-0.64)	-0.001 (-0.23)	0.14
	ln(LABOR+1) SOUTHERN	1.791		0.676 (7.57)	-0.052 (-2.26)	0.39
	ln(NONLAB+1) SOUTHERN	0.258	0.039 (2.48)	0.080 (2.62)	-0.000 (-0.04)	0.40
EARLY & MID	ln(LABOR+1) NORTHERN	11.416		0.196 (4.00)	-0.066 (-4.09)	0.19
	ln(NONLAB+1) NORTHERN	-0.301	0.167 (7.56)	0.070 (2.55)	0.013 (1.45)	0.16
	ln(LABOR+1) SOUTHERN	2.413		0.187 (2.12)	-0.052 (-2.22)	0.41
	ln(NONLAB+1) SOUTHERN	-0.007	0.019 (1.30)	0.033 (1.55)	-0.000 (0.55)	0.15
GRAPEFRUIT	ln(LABOR+1) NORTHERN	0.193		0.336 (3.84)	-0.017 (-0.59)	0.20
	ln(NONLAB+1) NORTHERN	0.149	0.765 (11.99)	-0.036 (0.070)	-0.005 (-0.29)	0.71
	ln(LABOR+1) SOUTHERN	0.911		0.203 (1.41)	0.003 (0.08)	0.15
	ln(NONLAB+1) SOUTHERN	0.013	0.001 (0.04)	0.021 (1.05)	-0.000 (-0.03)	0.01
SPECIALTY FRUIT	ln(LABOR+1) NORTHERN	1.511		0.387 (5.15)	-0.061 (-2.46)	0.51
	ln(NONLAB+1) NORTHERN	-0.079	0.023 (2.54)	0.031 (2.27)	0.003 (0.57)	0.09
	ln(LABOR+1) SOUTHERN	2.926		0.322 (2.83)	-0.068 (-2.08)	0.45
	ln(NONLAB+1) SOUTHERN	-0.240	0.069 (3.39)	0.066 (1.73)	0.003 (0.29)	0.17
* VARIABLES USED: LABOR - PER ACRE LABOR COSTS NONLAB - PER ACRE NONLABOR COSTS DUR28 - TIME IN HOURS THAT THE TEMPERATURE WAS BELOW 28° MINFOR - MINIMUM TEMPERATURE FORECAST						

year's data base and performing the regressions as described above. Second, since it was determined that minimum temperature forecasts are a useful predictor of costs, such forecasts will have to be artificially generated in the historical data. This can be done in a straightforward manner by generating forecast errors in a Monte Carlo framework, as the historical years are "played" through the statistical relationships. The forecast error distribution parameters for the "with" and "without" forecast improvement techniques can be obtained from the statistical analyses of forecast accuracies described in Section 4.

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6. ASSESSMENT OF CONTROL GROUP RESULTS

6.1 1976-77 Frost Season

6.1.1 Conditions for Florida Citrus in 1976-77

Florida experienced its first major freeze since 1971 in the winter of 1976-77. On the night of January 18, southern counties of Florida experienced the first snowfall since weather records began over 60 years ago. During the period November 1, 1976 through March 1, 1977, there were 26 nights on which the minimum temperature forecasted was 28°F or below in some part of central Florida.

The effects of the unusually severe winter of 1976-77 on the citrus industry and on the control group in particular were impressive. A record citrus harvest had been forecast by the Florida Crop and Livestock Reporting Service before the big freeze occurred. It is estimated that approximately 14 percent reduction in supply (from 217 million boxes to 186 million boxes) occurred due to the January freeze. Further reductions were observed later due to lower yield in pounds-solid per box. Prices increased markedly, nearly doubling after the January freeze, offsetting the growers' fruit losses in many cases. Gains from price increases exceeded losses from fruit damage for the industry as a whole, although certain sectors, notably limes and tangerines, were badly hurt.

6.1.2 Trends in Florida Citrus Protection Against Freezing Temperatures

High fuel prices have been a reality since 1973. The cost of oil for fueling orchard heaters is currently a significant part of the total production cost of citrus on protected acres. Some growers, in early winter 1976, faced with low prices for citrus fruit and high prices for fuel oil, decided to forego protection of fruit, or at

least to stop protecting their fruit after the existing stocks of oil were depleted. The continuing trend towards less protection of citrus fruit was noticeable to county extension agents, such as John Jackson. On the other hand, protection of the trees (at 22°F or less) is clearly desirable even at high fuel costs. Loss of a tree affects the grower's income for many years, and is not offset by salvage operations and higher post-freeze fruit prices. Freezes which damage large numbers of citrus trees in Florida are relatively rare; the last one before the January 1977 freeze was in 1962. Thus the grower can rationalize the high expenditure for protection of the citrus orchard as an extraordinary one, and, averaged over 15 years, it is quite acceptable. Protection of the fruit (at 28°F or lower) is indicated several nights per season, and thus the current expenditure for fuel oil must be included as part of the seasonal production cost. As such, it is essential for the grower to analyze carefully the decision to protect fruit in terms of the price expectation for the fruit after the freeze with and without protection, relative to the cost of protection. During the data collection process, several growers informed ECON that they did not consider it economical to protect citrus fruit in the winter of 1976-77. They may since have changed their minds in the light of substantial increases in citrus prices and the severity of the winter weather in Florida.

6.1.3 Experimental Results

The costs and losses reported in Section 5 reveal that protection of citrus orchards was practiced in the experimental sample^{*} in 1976-77 (the control group) and was generally worthwhile for the growers. The total reported cost of protection for the control group was \$473,200; net gains for the control group due to price increases after accounting for losses due to freeze damage were

^{*}Nearly 100 percent of the sample had protection capability.

\$1,168,000. Table 6.1 shows the breakdown of the costs and losses by county. The results are unique for Highlands county, this being the only case in the control group showing a net loss. Most of the net loss in Highlands was due to the damage to temples which, in spite of the freeze damage, experienced only a small price increase, from \$2.40 to \$2.80 per box. Another factor in the Highlands loss was the lack of adaptability of fresh temples to processed, which for other varieties of citrus allowed much of the freeze-damaged fresh fruit to be sold to processors. In contrast, the tangerines in Hillsborough County, which also suffered considerable damage, showed a dramatic price increase from \$0.80 to \$5.05 per box. Clearly the sensitivity of the market to supply reductions, as well as the sensitivity of the fruit to freezing temperatures must be taken into account by the grower in forming his decision to protect citrus acreage.

6.2 1977-78 Frost Season

6.2.1 Conditions for Florida Citrus in 1977-78

During the 1976-77 frost season, many citrus trees sustained significant damage. Although trees bearing early and midseason oranges were in general

Table 6.1 Comparison of Reported Costs of Protection and Net Gains Due to Price Increase After Accounting for Freeze Damage Losses: The 1976-77 Control Group			
County	Total Costs of Protection (\$)	Net Gains (\$)	Ratio
Hillsborough	63,000	247,600	3.93
Polk	206,900	216,400	1.04
Orange	81,500	254,000	3.12
Lake	73,700	331,100	4.49
Marion	6,100	30,100	4.93
Osceola	13,600	148,000	10.88
Highlands	14,100	-87,800	-6.23
Hardee	14,300	30,600	2.14
Total	473,200	1,168,000	2.47

damaged less severely than other varieties, forecasts for 1977-78 production of round oranges were 12 percent below 1976-77 production and 23 percent below pre-freeze expectations for 1976-77. The weather, however, was mild during the winter of 1977-78 and contributed to production slightly in excess of forecasts. Only two days, January 16 and February 22, showed significant low temperatures, but even on those days the duration of the cold was not long enough to cause much damage except in the coldest localities. The Florida Crop and Livestock Reporting Service attributed no box loss to figures in the past season, and less than a 2.5 percent orange juice yield drop was reported. Prices, which began the season at a relatively high level due to supply shortages during the 1976-77 season, remained high and fairly stable throughout the 1977-78 season.

6.2.2 Trends in Florida Citrus Protection Against Freezing Temperatures

Expectations that higher prices for citrus would lead to a change in protection activity on cold nights were discounted by growers and by county extension agents, who indicated that it was business as usual for the growers this year. Higher fuel prices were again expected to contribute to a continuing trend toward less protection of citrus fruit. Because the 1977-78 season was a mild one, it was difficult to assess the actual impact of higher citrus prices and higher protection costs on the grower's protection decisions.

6.2.3 Experimental Results

The protection costs reported in Section 5 reveal that in spite of mild winter weather, some protection activity was undertaken by growers in the experimental sample in 1977-78. Most of the costs incurred by growers can be attributed to minor frost/freezes on the nights of January 15 and February 22, 1978, although a significant fraction of the growers also initiated limited protection activity on January 10, 1978. Total costs for protection in the sample group amounted to approximately \$128,000. Table 6.2 shows the breakdown of these costs by county.

Table 6.2 Protection Costs: The 1977-78 Control Group	
County	Total Costs of Protection (\$)
Hillsborough	10,881
Polk	35,817
Orange	23,471
Lake	29,133
Marion	8,864
Osceola	15,983
Highlands	1,768
Hardee	1,738
Total	127,655

Grower reports indicated that losses due to frost/freeze during 1977-78 were so low that they could hardly be quantified. Some growers reported a small decline in juice yields over the season, but none experienced any significant box losses. No tree damage was reported. Because of the lack of hard data relating to frost damage in the past season, losses were treated as negligible in the experimental data base for 1977-78.

6.3 Comparison of 1976-77 and 1977-78 Results

The two seasons for which experimental data has been collected and analyzed were fundamentally very different. The first was an extremely cold winter with large protection costs, significant losses and wide price fluctuations. The second was moderately mild, with lower protection costs, essentially no losses attributable to cold weather and stable prices.

Because of the very different character of the two seasons, the statistical cost and loss relationships estimated were substantially different. This does not necessarily mean that there was a real change in the response of the growers to cold temperatures or in the interactions of price, supply and demand within the market for citrus. As an illustration, consider a scatter plot of per acre protection costs versus frost severity, and shown in Figure 6.1. Each point represents a hypothetical observation for a particular grove and cold night during either the 1976-77 or 1977-78 cold season. In the first season, costs and severities were of relatively large magnitude, resulting in many observations in the upper right portion of the scatter plot. The 1976-77 data base also yielded some low cost and severity points, and a few in the middle range. In contrast, the observations from the warmer second season fall almost totally in the lower left portion of the

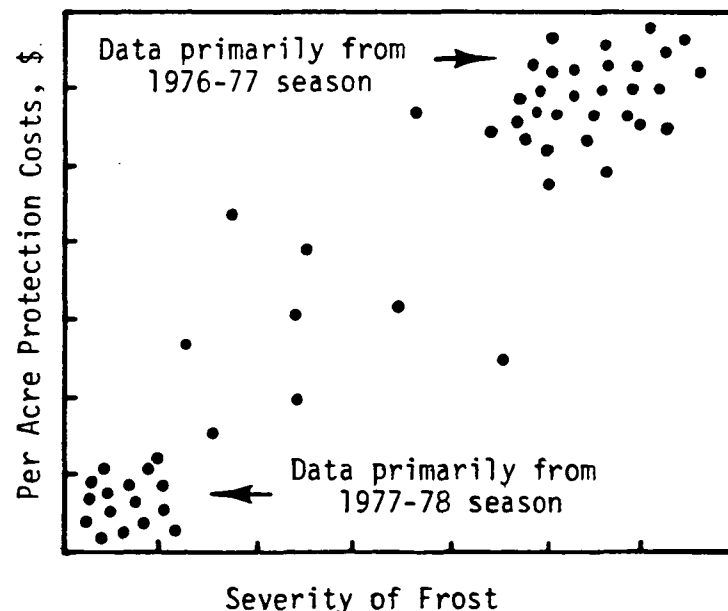


Figure 6.1 Scatter Plot Illustration: Severity of Frost Versus Per Acre Protection Costs

scatter plot, since costs and severities were generally close to zero. The regression lines estimated for each frost season individually represent the best fit to each cluster of points. Because the clusters overlap very little, it is not surprising that the estimated statistical relationships between cost and severity for each year are somewhat different. An overview of the results from the two years indicates that the 1977-78 experimental data base may provide data which would beneficially augment the 1976-77 data base. However, further statistical work of a comparative nature needs to be done to determine whether the two sets of experimental data can indeed be joined to form one consistent control group sample. Preliminary analyses indicate that the two sets may be combined.

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7. PLAN FOR 1978-79 TEST GROUP MEASUREMENTS AND ANALYSES

In order to estimate the benefits that may be realized by the citrus growers as a result of improved frost forecasting capability, control and test groups have been established. Effective separation between the two groups of sample growers is accomplished temporally. The control group, utilizing current forecasting capability, was observed during the 1976-77 and 1977-78 frost seasons. The test group, benefiting from improved frost forecasting capability which will result from the utilization of SMS/GOES data in combination with forecast models being developed by the University of Florida, will be observed during the 1978-79 frost season. The economic benefits of the improved forecasting capability will then be the difference between the normalized costs and losses of these two groups extrapolated across the state of Florida.

During the previous year's activity, the details of the experiment design were developed, data collection methodology and procedures were determined, control group data collection undertaken and completed, data reduction techniques developed and implemented, and economic analyses undertaken. The previous year's work also resulted in the development of the experiment sampling plan, the methodology for establishing protection costs and losses resulting from inadequate protection in terms of temperature forecasting capability, and the development of the means for collecting data which would demonstrate the economic consequences of improved temperature forecasting.

ECON established a sampling plan concerned with the determination of the specific growers (and groves) who would participate in the conduct of the experiment. Specific grower selection considered the desired number of samples to

be included in the test and control groups. This included consideration of the accuracy of the data and the segmentation requirements (in terms of geographic location, frost protection practices, soil types, citrus crop types, etc.). A major consideration was County Extension Service experience with growers and the population of growers which was expected to be cooperative. The sampling plan concept was developed and reviewed with the county extension agents and resulted in a selection of growers who participated in the experiment. After completion of the determination of grower data requirements and data forms, discussions were held with the growers to make a final determination of which growers would participate in the experiment. As part of this initial effort, the specific procedures of data gathering were determined, including the role of information provided by the National Weather Service, the County Extension Service, the University of Florida, the Federal Crop Insurance Corporation and the citrus growers.

Cost and loss determination methodologies were determined and detailed citrus grower and National Weather Service data requirements were determined. These data requirements were reviewed with the County Extension Service, Citrus Growers Association and National Weather Service. The result was the determination of the specific data needs matched with the availability of data from the growers and the National Weather Service. Finally, data forms were developed which placed emphasis upon minimizing the data collection burden on the grower. Three data forms were developed:^{*} one to gather data which remained invariant during the frost season; one to gather data on the daily protection costs, events, decisions and actions; and one to gather data on fruit and tree damage. These

^{*}These were modified during the second year of data collection so as to improve the efficiency with which the data was collected.

forms were filled out for each of the groves in the sample. Sources were also developed and data obtained for citrus spot and future prices, and fuel prices.

The cost and loss methodologies were used to determine average cost and loss per frost event per grove. The methodology allows a "normal" frost season to be defined in terms of number of days of different levels of frost severity. Normalized annual costs and losses for both the control and test group are to be established, the difference between these costs and losses will be the annual benefit of the improved forecasts to the citrus growers comprising the sample. Procedures have also been developed for extrapolating these results across the Florida citrus industry, taking into account grower location, frost protection practices, and frost occurrences.

Methods and procedures were developed for establishing a frost severity index based upon the duration of different levels of frost and its impact (damage) on fruit and trees. This requires knowledge of the grove temperature (as a function of time) that would have occurred in the grove if protective action were not taken. To accomplish this, methods were devised for relating National Weather Service control thermometer thermographs to grove temperature (for each grove in the data base) which are then used to establish the grove frost severity index for each night of frost.

The developed data collection procedures were implemented for a control group consisting of 245 groves. With the assistance of the County Extension Service and as a result of the 1976/77 frost season, Grove Background Reports were obtained for the 245 groves; 2150 Nightly Frost/Freeze Protection Activity Reports were obtained, as were 287 Damage Reports. Also with the assistance of the County Extension Service and as a result of the 1977/78 frost season, Grove

Background Report updates were obtained for 195 groves; 2884 Nightly Frost/Freeze Protection Activity Reports were obtained, as were 61 Damage Reports. Additional data was provided by the Florida Crop and Livestock Reporting Service and the Federal Crop Insurance Corporation. The NWS provided all necessary weather forecasts and control thermometer thermographs. In addition, the NWS has provided detailed temperature records of the past 30 years so that a "normal" year could be ascertained for control and test group comparisons.

The collected data forms were reviewed, data transformed and entered into the computerized data base. This data base (of the control group) is utilized in the determination of events and average annual costs and losses. Daily costs and losses have been established for each grove and classified by event type, citrus grower type, minimum forecasted temperature and frost severity. Average costs and losses have been determined and annual costs and losses established for this control group. The capability which has been developed will allow the results of the control and test groups to be compared and the annual demonstrated benefits to be established. These benefits, based upon the sample population, will be extrapolated to total Florida citrus industry annual benefits, taking into account grower geographic locations, geographic temperature patterns, grower crop protection capabilities and crop type. The net result will be the establishment of demonstrated benefits and extrapolated (from the measured benefits) benefits which are the direct result of improved frost protection decisions made possible by improved temperature forecasting capability.

To summarize, the experiment for measuring the economic value of improved temperature forecasts to the Florida citrus growers has been designed, data requirements and data collection methods and procedures have been determined, and control group data collection completed. Two years of data have been

collected and analyzed. The data has been entered into a computer data base. The methodology for establishing annual costs and losses has been established and initial control group analyses completed. The preliminary control group results have been extrapolated to all applicable protected citrus acreage in Florida. It is this economic value (protection costs plus economic crop losses) which is to be compared with similar data to be obtained from the experiment test group. The test group data will be established during the 1978-79 frost season. Analysis of this data and comparison with control group results can then be established at a later date.

7.1 Statement of Tasks

The successful completion of the economic experiment requires that the following major tasks be completed: Data Collection, Data Reduction, Economic Analysis and Reporting. These tasks are described below along with a schedule (Figure 7.1) for their performance. It should be noted that current plans call for the data collection task to be completed by July 1979. A relative schedule for all other tasks is presented since only the data collection task has been approved as of this writing.

Task 1: Data Collection

The data collection task is concerned with gathering the necessary data from citrus growers, the National Weather Service and other data sources, which will lead to the establishment of citrus grower test group results that can be compared with the previously developed control group results. In particular, a test group will be developed which will contain on the order of 200 groves. ECON will continue to work closely with the county extension agents and citrus growers in order to obtain the necessary (a) new or updated Grove Background Report data, (b) Nightly Frost/Freeze Protection Activity Reports, and (c) Damage Reports. ECON will

continue to work closely with the National Weather Service to ensure an orderly flow of daily weather forecasts and control thermometer thermograph data. ECON will also continue to obtain other necessary data such as spot and futures prices, fuel prices and other data necessary for the economic experiment.

Task 2: Data Reduction

The data reduction task is concerned with the review of all collected data (Grove Background Reports, Nightly Frost/Freeze Protection Activity Reports, Damage Reports, NWS daily weather forecasts, control thermometer thermographs, fuel prices, etc.) and transformation of the data into suitable form for entry into a general data base. As data is received, it must be reviewed for correctness and consistency. The data reduction task can be performed in two parts, the first of which is concerned with data correctness and consistency. This will be performed concurrently with the data collection task. The second part of the data reduction task is concerned with transformation of the data and entry into the general data base. This can be performed at some later date since all necessary data will have been collected.

Task 3: Economic Analysis

The economic analysis task is concerned with the determination of annual savings which occurs as a result of improved temperature forecasts and is based upon the data obtained from the citrus growers and the National Weather Service. Regression equations have been established for the control group that relate (1) production cost to minimum forecasted temperature and duration of temperature below 28°F and (2) citrus losses to frost severity. The economic analysis task is concerned with developing similar regression equations for the test group and comparing the results of the control and test groups. The comparison will be made by using NWS 30 years of temperature data at the control thermometers together

with the measured (during the control group and test group frost seasons) temperature forecast accuracy. It is therefore also necessary to establish the probability distribution of temperature forecast accuracy as this is required for the determination of protection costs. It is also necessary to establish frost severity for each frost night for each grove. The results of the control and test groups are to be compared and the annual demonstrated savings established. These savings, based upon the sample population, are to be extrapolated to total Florida citrus industry annual savings, taking into account grower geographic locations, geographic temperature patterns, grower crop protection capabilities and crop type. The net result will be the establishment of demonstrated benefits and extrapolated (from the measured benefits) benefits which are the direct result of improved frost protection decisions made possible by the improved temperature forecasting capability.

Task 4: Reporting

Both oral briefings and written reports will be provided. Oral briefings will be given as required. Monthly activity reports will be provided. A final report will be provided and will describe in detail the methodology, the data collection techniques, the collection data (growers, NWS and others) and established results.

7.2 Schedule

The schedule of events for the completion of the Florida citrus crop economic experiment is illustrated in Figure 7.1. The schedule, to a large extent, is dictated by the Florida frost season, which extends from December through March, during which most of the necessary data must be obtained. It is anticipated, based upon the collection procedures and experience with the control group, that data collection will continue through July (since Damage Reports are prepared shortly after harvest time and harvesting extends through June). The

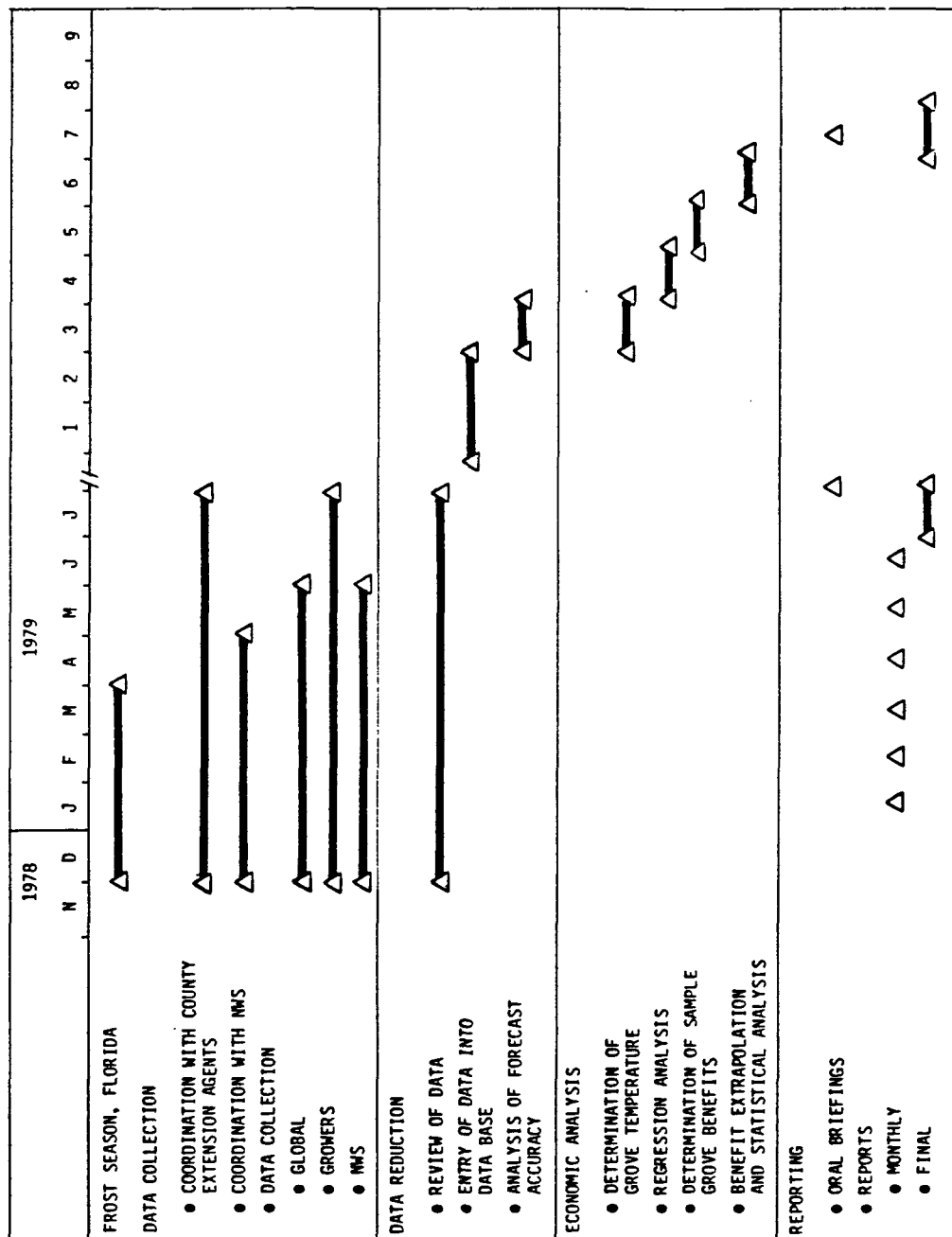


Figure 7.1 Schedule of Events for Completion of Florida Citrus Crop Economic Experiment

initial part of the data reduction task will overlap the data collection task. The final portion of the data reduction task can be accomplished at a later date but must precede the economic analysis task. The initial portion of the economic analysis task will be devoted to analyses which insure that valid results will be obtained in spite of the temporal separation of control and test groups (for example, it will be necessary to consider the impact of citrus prices on protection decisions if significant price differences are noted at the start of and during the control and test group frost seasons). As test group cost and loss data become available, attention will focus on the determination of costs and losses and savings which may result from the improved forecasts.

The schedule indicates the specific tasks currently planned for completion during the December to July time period. The schedule also indicates the duration of other tasks that are required to complete the analysis and comparison of the control and test groups. The time frame of these tasks is indicated in terms of months from when approval is received to start these tasks. It should be noted that if these tasks are approved prior to May, the total duration of the efforts may be reduced by about three months since the indicated tasks may be partially overlapped.

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APPENDIX A

PHYSICS AND PHYSIOLOGY OF FROST PROTECTION

A.1 Introduction

The last few decades have seen important progress in our understanding of the nature and mechanism of freezing injury in plant cells. Though the relationship between freezing and plant cell damage has been studied with reference to the microclimate of the plant, the relationship between the weather and damage to fruit in a grove has not been studied vigorously. In this section, fruit losses are related to weather variables and the effect of frost protection in reducing damage. The approach is one of obtaining a normative model based on different heat transfer mechanisms involved.

Heat transfer is the basic physical process involved in frosts and freezes that are the result of the transfer of terrestrial heat from the ground to the atmosphere further out in space. The three methods by which heat is transferred are radiation, convection and conduction. Work by Crawford^{*} and Gerber^{**} have made it possible to arrive at much closer estimates of heat loss and the heat requirements for protection for any particular freeze. This is accomplished by developing a mathematical model of the heat balance in the orchard layers. The model's equations have been solved and transformed into nomograph form for quick solutions for frost protection problems.

The crop zone is defined in three dimensions and is visualized as a box. The floor of the box is the area being heated (if heaters are used) and is square; the

^{*}Crawford, T. V., "Computing the Heating Requirements for Frost Protection," Jour. Appl. Meteor., 3 760-60, 1964.

^{**}Gerber, J. F., "Methods of Determining Nocturnal Heat Requirements of Citrus Orchards," Proc. Frost International Citrus Symp. II; 545-550, 1969.

depth of the box is determined as the height to which heating has an effect. Heat losses are by:

- Radiation to the sky
- The air that moves through the upwind wall of the box, advection
- Induced flow of cold air drawn from the sides of the box as a result of the difference in relative buoyancy between heated and unheated areas.

Thus, total heat loss, H , is given by

$$H = \text{advection loss} + \text{induced flow loss} + \text{net radiation loss}.$$

The advection, induced flow and net radiation terms can be obtained using the nomographs developed by Crawford (Figures A.1 and A.2).*

Consider the heat loss of a single fruit. Heat is transferred from the inside of the fruit to the surface by conduction. The surface of the fruit, leaves and trunk lose heat to the atmosphere by radiation and by convection. When heating devices or wind machines are used in the grove, heat can be gained by radiation and convection. When temperatures fall well below a threshold temperature, then the fruit loses some of its latent heat and freezes. Each of these effects is analyzed in the following paragraphs.

A.2 Thermal Conduction

Thermal conductivity plays an important role in the freezing of fruit. The rate of heat loss, Q , at steady state is given by

$$Q = k A \theta \frac{(T_1 - T_2)}{d}$$

where

* Ibid.

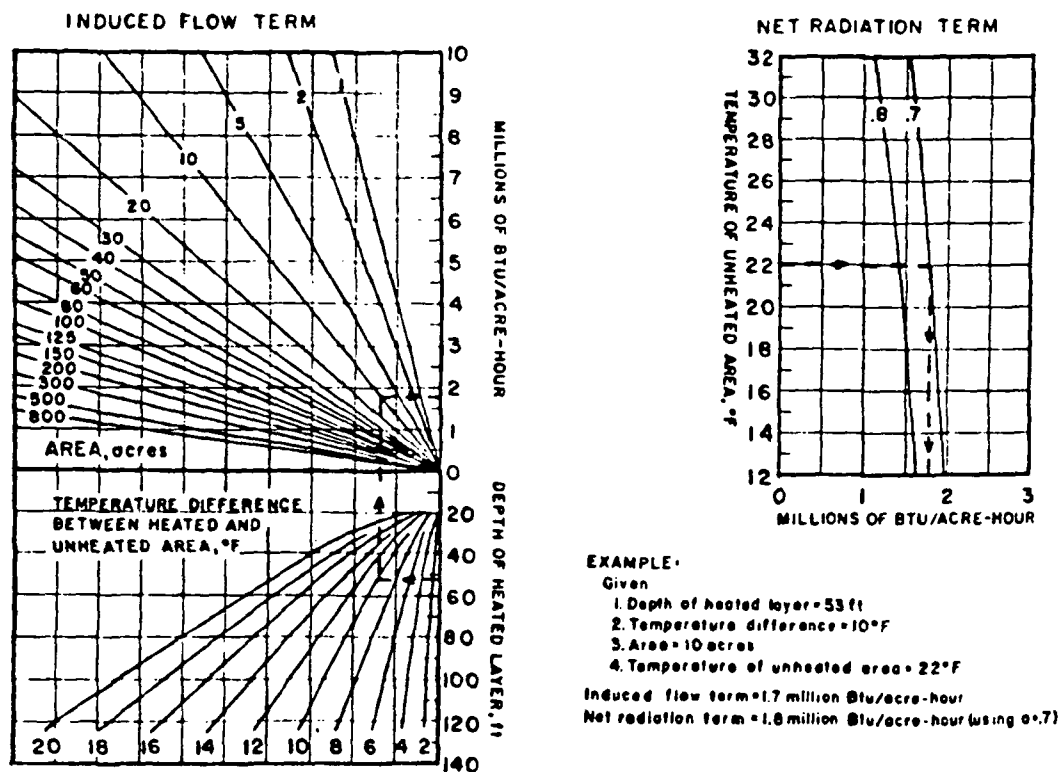


Figure A.1 Nomographs for Determining the Magnitude of the Induced Flow Term and the Net Radiation Term in a Heated Citrus Orchard (Crawford, 1964b)

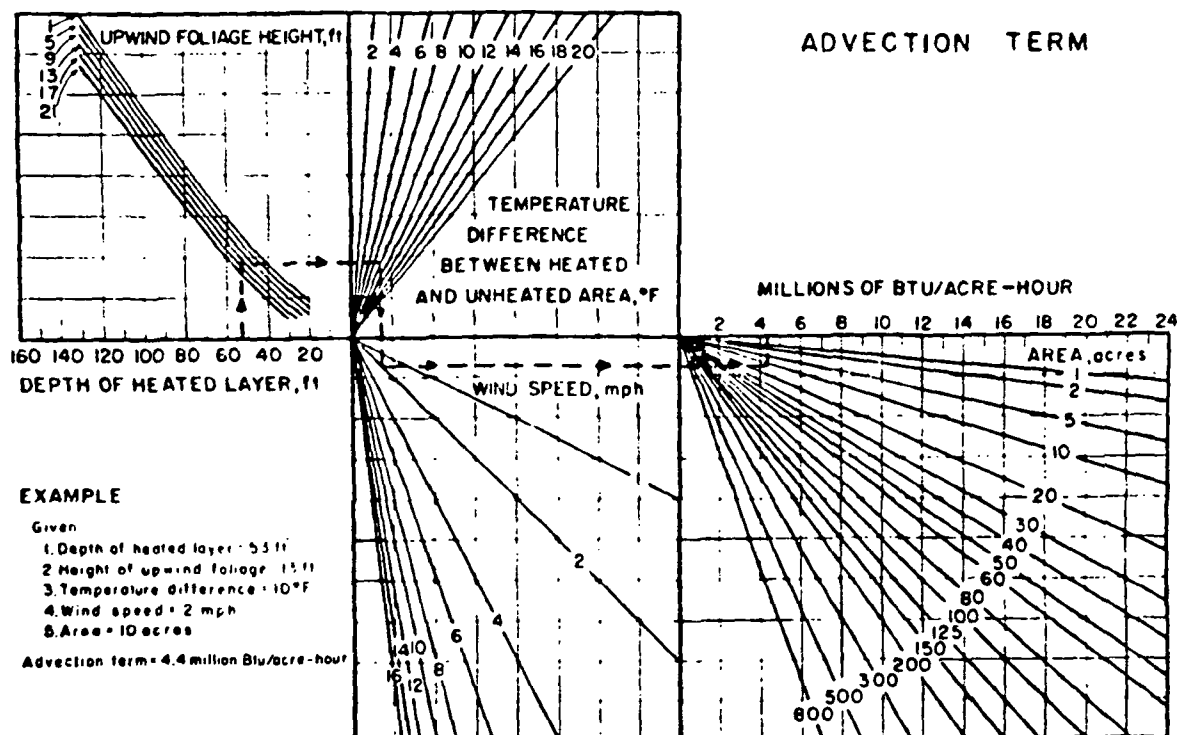


Figure A.2 Nomograph for Determining the Advection Term in a Heated Citrus Orchard (Crawford, 1964b)

- Q = heat loss at steady state, cal.
 K = thermal conductivity, $\text{cal cm}^{-2} \text{sec}^{-1} \text{ } ^\circ\text{C}$ per cm
 θ = time, seconds
 d = distance through conducting medium, cm
 A = surface area, cm^2
 T = temperature, $^\circ\text{C}$.

Freeze damage is proportional to the amount of heat lost below a certain threshold temperature, T_h . Thus, if the actual temperature at time t is $T_a(t)$, heat loss due to conduction for a single fruit j can be calculated by

$$Q_j = \int_{t_h}^{t_a^*} \frac{kA_j}{d_j} (T_h - T_a(t)) dt$$

where

subscript j refers to a single fruit j

t_h = time at beginning of freeze

t_a^* = time at end of freeze.

Let $T_h - T_a(t) = \nabla T_a(t)$

Then,

$$Q_j = \int_{t_h}^{t_a^*} \frac{kA_j}{d_j} \nabla T_a(t) dt$$

Heat loss by all the fruit in the orchard is

$$Q = \sum_{j=1}^n \int_{t_h}^{t_a^*} \frac{kA_j}{d_j} \nabla T_a(t) dt$$

$$Q = k \cdot \left(\sum_{j=1}^n \frac{A_j}{d_j} \right) \cdot \int_{t_h}^{t_a^*} \nabla T_a(t) dt.$$

$\int_{t_h}^{t_a^*} \nabla T_a(t) dt$ is equal to the degree hours below the threshold temperature.

Thus, heat loss is directly proportional to degree hours. Since the enthalpy of fruit is directly proportional to fruit size, smaller fruit is expected to have more damage than large fruit. The preceding analysis would suggest that fruit damage is a function of the size distribution of the fruit and the degree hours below a threshold temperature. Since citrus is a seasonal product, the size distribution can be stated in terms of the time of the year.

A.3 Convection Gains and Losses

Consider the effects of convection in an orchard. Heat gain or loss due to convection occurs when there is turbulence due to wind. Because air is a poor conductor of heat, air at a solid surface forms a surface boundary layer which resists the transfer of heat. However, when there is a temperature difference between the solid surface and the air, it leads to free convection. When a leaf or fruit loses heat by radiation to a cold sky, it will be colder than the air around it, resulting in some heat transfer from the air to the leaf or fruit. The heat gained will be transferred by free convection.

Forced convection occurs when natural winds move with velocities above 2 to 5 miles per hour, or when wind is produced with an electric fan, wind machine or blower. Both naturally and artificially produced winds may develop turbulence in contrast to laminar flow across surfaces of leaves, fruit and branches. Plant parts are extremely sensitive to air movement, the heat transfer in citrus increasing

linearly with the air velocity over a limited range. The advective loss of heat, AC_{fa} , between fruit and air due to wind is given by the equation:

$$AC_{fa} = 1.97 + 0.047 v$$

where v equals velocity of wind. This equation is developed from Raschke* and establishes the linear proportionality between wind velocity and heat loss.

When there is very little wind (wind speed below 10 cm/sec), the convection loss, CC_{fa} , is given by the equation:

$$CC_{fa} = \frac{\beta (T_a - T_f)^{0.25}}{D}$$

A.4 Radiation Gains and Losses

The primary heat loss in an orchard is radiation to the upper atmosphere from the air at foliage level, the fruit and the ground.

Let

U refer to the upper atmosphere

A refer to the air at foliage level

F refer to the fruit

G refer to the ground

H refer to heaters

L refer to the leaves.

Let T_U , T_A , T_F , T_G , T_H and T_L be their corresponding temperatures in °K. Also, let subscripts i and j denote any two of these bodies. Then the radiant heat transfer between them, R_{ij} , is given by

$$K_{ij} = \epsilon \sigma \frac{(T_i^4 - T_j^4)}{T_i - T_j}$$

* Raschke, K., "Heat Transfer Between the Plant and the Environment," Ann. Rev. Plant Physiol. 11-111-26, 1960.

where

ϵ = emissivity

σ = Stefan-Boltzman constant

T_i, T_j = temperatures of bodies i and j, °K.

Fruit, leaves, air and ground temperature are fairly close to each other and the effect of radiant heat transfer between them is quite negligible. However, the radiant heat transfer between these bodies and the upper atmosphere results in a net heat loss from the orchard. The drop in temperature in an orchard is due to this loss in a radiation freeze, and can be measured. The surface temperature, if the fruit is assumed to be the air temperature, can also be measured. Simultaneously, when the heaters in a grove are operating, there is heat transfer from the heater to the fruit and leaves. This effect is analyzed in the following paragraph.

A.5 Effect of Heaters and Wind Machines

The principle means of heat transfer by heaters is by radiant energy. Thus, the rate of heat absorption by the fruit, R_{HF} , is given by

$$R_{HF} \approx C_1 \epsilon \sigma \frac{(T_H^4 - T_F^4)}{T_H - T_F}$$

where C_1 is a constant of proportionality dependent on the fraction of fruit exposed to the heater.

This can be rewritten as

$$\begin{aligned} R_{HF} &\approx C_1 \epsilon \sigma \frac{(T_H^2 + T_F^2)(T_H^2 - T_F^2)}{(T_H - T_F)} \\ &\approx C_1 \epsilon \sigma (T_H^2 + T_F^2)(T_H + T_F) \end{aligned}$$

Let $\rho = \frac{T_F}{T_H}$

$$R_{HF} \simeq C_1 \epsilon \sigma T_H^3 (1 + \rho^2) (1 + \rho)$$

The heater temperatures range from 600°F to 1200°F but is fixed for a given heater. However, the temperature of the fruit fluctuates between 20°F to 30°F. Converting to °K, it can be seen that the variation in the value of ρ is very small. For an average heater, $\rho \simeq 1/3$.

Thus,

$$R_{HF} \simeq C_1 \epsilon \sigma \cdot \frac{3}{2} \cdot T_H^3$$

Similarly

$$R_{HL} \simeq C_2 \epsilon \sigma \cdot \frac{3}{2} T_H^3$$

With constant heater temperature, the radiant heat transfer rate is a constant.

Hence, the total heat gained is proportional to the duration of use of the heater.

Only fruit and leaves in direct unobstructed line of sight of the heaters receive radiant heat. Thus, a fraction of the fruit and leaves receive radiant heat and the others do not. Since the fraction receiving heat is a function of the spatial distribution of the heaters in the grove, this is a constant for each grove. Empirically it is found that the energy absorbed by the trees is about a third of the energy generated. The sky and the ground absorb the remaining energy equally.

The purpose of wind machines is to produce enough turbulence to break up the temperature inversion of the air, mix the warm and the cold components, transport the mixture and, at the same time, push the cold air out of the area. Let

T_a = temperature of air at foliage level

T_s = temperature of air at upper stratification of thermal inversion.

With wind machines,

$$T'_a \approx T_a + e_w \frac{(T_s - T_a)}{2} \quad 0 \leq e_w \leq 1$$

where

T'_a = increased temperature of air

e_w = effectiveness of wind machine mixing.

At steady state with constant difference in temperature between layers, the total heat transfer is proportional to time.

A.6 Aggregation of All Heat Transfer Effects

Frost and freeze damage to fruit is a result of heat transfer from the fruit. The primary cause of damage during a radiation freeze is the loss due to conduction of heat to the surface of the fruit. In an advective freeze, the primary reason for the damage is desiccation.

Thus, combining the effects of heat gains and losses, for a radiational freeze, fruit damage, D_f , can be written as:

$$D_f = \gamma \left[\left\{ \int_{t_h}^{t_a^*} \nabla T_a(t) dt \right\} \left\{ \sum_j \frac{kA_j}{d_j} \right\} - C_1 \Delta t - (\Delta T_i) \epsilon_w \Delta t \right]$$

where γ is the constant of proportionality between heat loss and damage.

The first term in the expression is the effect of heat loss due to conduction. The second term is the effect of heat gain due to heaters. The third term in the expression is the effect of heat gain due to wind machines.

In a simplified form, the expression can be written as

$$D_f = a_0 + a_1 (^\circ\text{hr}) - a_2 (\text{hr})$$

where

- a_2 = is the coefficient of the reduction in damage due to heaters and wind machines. It is proportional to time.
- a_1 = is the coefficient of the damage due to severity of the freeze. This is proportional to degree-hours.
- a_0 = is the systematic bias due to misspecification of damage threshold temperature.

APPENDIX B
CITRUS GROWER DATA FORMS
PACKAGE
(1976-77)

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NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

Mr. John Smith
999 Citrus Road
Orange City, Florida

Dear Mr. Smith:

As you are probably aware, the National Aeronautics and Space Administration, National Weather Service and University of Florida are developing techniques which will lead to improved temperature and frost/freeze forecasting by making use of thermal mapping from the SMS/GOES satellite. It is anticipated that these efforts will lead to an operational capability prior to the start of the 1977/78 frost season. An experiment has been initiated to measure the economic benefits which may occur to the Florida citrus growers as a result of the improved temperature and frost/freeze forecasting. This is a somewhat unique opportunity in that a direct attempt is being made to measure and evaluate the economic benefits which may result from a research and development program. It is hoped that the results of this experiment will provide an added stimulus for further research and systems aimed at improving the various aspects of meteorological forecasting.

Your County Extension Agent, Tom Oswalt, has advised us of your willingness to cooperate in this experiment. We want to thank you since this experiment would not be possible without your cooperation and the cooperation of other citrus growers. It is anticipated that approximately fifty growers will participate in the experiment and will provide data on a total of several hundred groves. This level of cooperation will allow the economic benefits to be measured for the experiment population and thence carefully projected across the Florida citrus industry.

ECON, Inc., a Princeton, NJ based economics and policy research and consulting firm, has overall responsibility for the planning and conduct of the economic experiment. We will be ably assisted by the Florida Cooperative Extension Service, University of Florida and the National Weather Service. We look forward to a very informative and successful experiment.

The experiment, in general, will be concerned with measuring the citrus protection costs and losses throughout the frost season. It is anticipated that the costs and losses will be measured during the current and the 1977/78 frost seasons. During the current frost season the NWS will provide temperature and frost/freeze forecasts in their normal manner. During the 1977/78 frost season the NWS will have available improved temperature data

obtained from the SMS/GOES satellite and improved forecasting techniques developed by the University of Florida. It is anticipated that the differences in forecasting capability will result in reduced grower protection costs and losses. The economic benefits are thus the differences in the growers costs and losses during the two frost seasons properly adjusted for differences in the severity and number of frost/ freeze occurrences.

Your County Extension Agent has given you a looseleaf book containing a set of report forms and instructions for filling out these reports. Three different report forms are provided, namely

- (1) a Grove Background Report, to be filled out once per frost season at the start of the frost season,
- (2) a Nightly Frost/Freeze Protection Activity Report, to be filled out if the NWS frost bulletin predicted temperatures of 28°F or less, and
- (3) a Damage Report, to be filled out when there is fruit and/or tree damage.

A set of these reports must be filled out for each grove for which you will be providing data. All data will be treated as confidential. A set of self-addressed and stamped envelopes is also provided. These should be used for mailing all reports at the end of each week to Tom Oswalt. If you have any questions upon reviewing the contents of the looseleaf book or throughout the course of the experiment, please contact Tom Oswalt. If further information is required the undersigned should be contacted (call collect: 609-924-8778).

At the end of the frost season and after all the data has been analyzed we anticipate providing you with a report which summarizes your protection costs and losses for each grove for which you provided data. This report will indicate how your costs and losses compared with the average cost and losses of all other groves which are similar to yours.

Again, we want to thank you for your cooperation. We believe that, through cooperative efforts such as this, the value of space technology can be correctly assessed and future research and new systems oriented toward helping to solve real problems.

Sincerely,

Joel S. Greenberg Director,
Techno-Economic Analyses

JSG/jmw



NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

FLORIDA CITRUS EXPERIMENT

to measure the value of improved
frost/freeze forecasting

Instructions and forms for the Florida Citrus Experiment
in the following order:

1. Instructions for the Grove Background Report
(Green)
2. Grove Background Report (Green)
3. Instructions for the Nightly Frost/Freeze
Protection Activity Report (White)
4. Nightly Frost/Freeze Protection Activity Report
(White)
5. Instructions for Damage Report (Pink)
6. Damage Report (Pink)

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INSTRUCTIONS FOR THE GROVE BACKGROUND REPORT

The questions in this grove background report refer to specific information about one grove only. Most of this information will not change from December to March. The background report questions are answered once only at the beginning of the winter season

"Grove"

For the purpose of this study, a "grove" is defined as a land area a) with citrus of the same variety, b) planted at the same time (except resets), c) having a uniform degree of frost/freeze protection and d) subjected to the same management and agricultural practices. If you have a large grove with a number of blocks, each of them with different variety of citrus, then these blocks would be called "groves" in this study.

"Grower"

A "grower" is considered to be a person who is in charge of the particular grove. In the case of an absentee owner it would be the grove manager or a person who is responsible for the grove management. That person would then fill out all data forms.

In order to avoid ambiguities and to minimize misunderstandings, the following is a brief explanation of how the questions in this report should be filled out.

1. Fill in the name which you have given to the particular grove. If you will be providing data for more than one grove, care must be taken to keep the data separately. To help in this separation you will find a list of grove I.D. numbers—please identify one of your groves with each of these I.D. numbers and maintain this list as a reference. This will be referred to each time a form is filled out. It is important to fill out one form for each grove. Each grove's assigned identification number will be used in the nightly reports.
2. Identify the location, section, range and township of your grove.
3. Circle one number which would identify a variety of citrus grown in this grove.
4. Circle one number which would identify the predominant type of rootstock of citrus grown in this grove.
5. Fill in the year in which the grove was planted. Do not fill in the year when the resets were planted.
6. If there are in this grove resets which are less than 7 years of age and not yet in full production or skips (trees which are out of production or empty spaces) then fill in the percentage of the total number of trees which they represent.
7. Specify the area of citrus bearing tree acres excluding the roads, empty spaces, etc. contained within this grove.

8. Identify the topographical location of this grove by circling the (one) applicable number.
9. Identify the soil type associated with the topographical location by circling the (one) applicable number.
10. If this grove is located near a lake, a river, or a reservoir which would influence your frost/freeze protection for this grove, then circle yes.
11. A control thermometer is a thermometer located in the vicinity of the grove which records the true temperature which would have occurred in the grove if the frost/freeze protection devices were not utilized.
12. The answer to this question would help us in a better understanding of your long-term frost/freeze protection strategy.
- 13-17. These questions pertain to the grove status and are self-explanatory. The average yield estimates for the past years would indicate if there was any damage of this grove due to frost or freeze and if it influenced your frost/freeze protection measures.
- 18-19. Answers to these questions would help in the better understanding how your marketing plans influenced your frost/freeze protection measures.
- 20-21. Describe the use of wind machines in this grove. List the various types of machines in this grove (example: single propeller, with tower mounted engine or an engine at base, dual wind machines with dual gasoline engines tower mounted, etc.) number of machines of each type used at the grove, the fuel type (gasoline electricity, propane), and their average rate of fuel consumption.
- 22-23. Describe the use of heaters in this grove. List various types of heaters (spot, jumbo cone, lazy flame 24 inch stack, lazy flame 18 inch stack, etc.), the number of heaters of each type used in this grove, the fuel type (diesel fuel, propane, etc.), and their average fuel consumption.
- 24-25. Try to estimate as accurately as possible the approximate amount of fuel on hand at the beginning of the frost/freeze season, indicate the storage capacity and the average price you paid for fuel especially if you have had this fuel for several years.
26. If you use any other kind of frost/freeze protection method for this grove, then circle an appropriate number.

This section records some specific information about one of the groves selected for this study. Most of this information will not change from December to March. Please be as specific as possible in answering these questions.

DESCRIPTION AND CHARACTERISTICS OF THE GROVE

1. Your own grove identification: _____
2. Grove location: _____ / _____ / _____
Section Township Range
3. Variety of Citrus grown in this grove: _____

CIRCLE ONE NUMBER

- 1 Early Oranges 6 Tangerines & Honey Tangerines
2 Midseason Oranges 7 Seedy Grapefruit
3 Late (Valencia) Oranges 8 White Seedless Grapefruit
4 Temples 9 Red-Pink Seedless Grapefruit
5 Tangelos 10 Some other variety; PLEASE SPECIFY: _____

4. Type of rootstock: 1 Rough Lemon 4 Trifoliolate Orange
2 Sour Orange 5 Carrizo Citrange
3 Cleopatra Mandarin 6 Other

CIRCLE ONE NUMBER

5. Year grove was planted: _____
6. Percentage of all trees that are resets less than 7 years of age or skips: _____ percent
7. Grove area (if possible be as specific as tenths of an acre of actual citrus bearing tree acres.): _____ acres

8. Grove terrain: 1 High Ground 2 Low Ground
3 Other; PLEASE DESCRIBE _____

CIRCLE ONE NUMBER

9. Grove soil type: 1 Ridge 2 Flatwoods
3 Other; PLEASE DESCRIBE _____

CIRCLE ONE NUMBER

10. Are there any large bodies of water which may influence your grove? 1 Yes 2 No
11. Is there a control thermometer associated with this grove which is outside of the protected area? 1 Yes 2 No
12. If you know the Federal Crop Insurance Corporation classification of this grove would you please write it down? _____

If you have any questions, call your county extension agent.

GROVE STATUS

13. Month of expected harvest: 1 January 7 July
2 February 8 August
3 March 9 September
4 April 10 October
5 May 11 November
6 June 12 December

CIRCLE ONE NUMBER

14. Average yield in this grove in the
- 1973-74 season: _____ boxes per grove
- 1974-75 season: _____ boxes per grove
- 1975-76 season: _____ boxes per grove
15. Estimate of yield for the 1976-77 season: _____ boxes per grove

16. Grove has experienced frost/freeze damage in the past three years which has reduced the grove's productivity or damaged the trees:

1 Yes When did this damage occur? Month: _____ Year: _____
2 No Month: _____ Year: _____
Month: _____ Year: _____

17. Did this damage prompt any additional frost/freeze protection measures for this grove? 1 Yes 2 No

MARKETING PLANS

18. At this time, do you intend to produce the citrus from this grove for fresh or processed market? 1 Fresh 2 Processed 3 Don't know

CIRCLE ONE NUMBER

19. What are the primary reasons you plan to market this fruit in this manner? 1 Variety or quality of fruit 2 Expected market price 3 Anticipated costs of freeze/frost protection 4 Other; PLEASE EXPLAIN: _____

CIRCLE AS MANY AS APPLY

FROST/FREEZE PROTECTION MEASURES

20. Wind machines used in this grove? 1 Yes 2 No...GO TO QUESTION 22

21. Wind machine data for this grove:

Type of Machines	Number of Machines	Type of Fuel	Average Fuel Consumption Rate*

*diesel.....gallons/hour
gasoline.....gallons/hour
electricity...kilowatts/hour
propane.....pounds/hour

22. Heaters used in this grove? 1 Yes 2 No...GO TO QUESTION 26

23. Heater data for this grove:

Type of Heaters	Number of Heaters	Type of Fuel	Average Fuel Consumption Rate*

*diesel fuel...gallons/hour
propane.....pounds/hour

24. Storage capacity and fuel on hand:

Type of Fuel	Storage Capacity	Fuel on Hand
diesel	gal.	gal.
propane	lbs.	lbs.
other		

25. Average price of fuel on hand; diesel fuel _____ ¢/gallons
propane _____ ¢/pound
other _____

26. Other frost/freeze protection methods used in this grove?

- 1 Yes —> What kind? 1 Permanent Oil Heating System
2 Sprinklers
3 Flood Irrigation
4 Other; PLEASE DESCRIBE: _____

OTHER INFORMATION

27. What other information can you provide that would be helpful in understanding the management of this particular grove?
PLEASE DESCRIBE _____

INSTRUCTIONS FOR THE NIGHTLY
FROST/FREEZE PROTECTION ACTIVITY REPORT

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The answers should be limited to one "grove" only (see Instructions for the Grove Background Report for the definition of a "grove"). You should fill out the nightly report everytime when a frost fruit bulletin by NWS forecasts the lowest temperatures to be 28°F or less even if you do not initiate any frost/freeze protection action. However, if you initiated some kind of protection during which you incurred costs then please fill out a nightly report regardless of the lowest predicted temperatures (i.e., even if the predicted temperatures were higher than 28°F).

1. Fill in your own identification of this grove and the I.D. number which was assigned to this grove.
2. Fill in the date.
- 3-4. Answers to these questions would provide information about which of NWS forecasts influenced your decision to initiate some kind of protective action and the degree of confidence you have in the NWS forecasts.
5. Specify if any action associated with frost/freeze protection was taken which lead to a financial cost to you including:
 - a) calling in laborers (seasonal or high school students) and paying them wages even if they do not perform any work and are later sent home,
 - b) asking some members of your permanent staff to perform activities associated with frost/freeze protection (such as monitoring the weather, checking and preparing the equipment, operating the wind machines, etc.) for which they are paid extra beyond and above their regular wages.
6. Labor costs have to be prorated to the one grove for which the nightly report is filled in. This is especially important when your crews fire and extinguish heaters in several groves of various sizes. Each one of these groves can be protected by different number of heaters requiring different amounts of time for their firing and extinguishing. Please take this into account when answering this question.
7. This grove can be protected by wind machines of different types which were turned on and off at different times. A group of wind machines are all wind machines of the same type, having the same rate of fuel consumption and which are turned on and off at the same time. If you, for example, have four machines of the same type, but two of them were turned off at 7 a.m., then there are two groups: fill two in Group 1 and two in Group 2 with the appropriate times of turning on and off.

It may take some time to turn on and off several wind machines of one group. It is assumed that turning them on is done in the same sequence as turning them off and therefore all machines are in operation approximately the same time. The recorded times on the nightly report are those times at which the first machine in a group was turned on and off, respectively.

8. The same concept as was used for wind machines applies for heaters. A group of heaters are all heaters of the same type, having the same rate of fuel consumption and which are turned on and off at the same time. Example: a grove is heated by forty heaters. Twenty are fired at 1 a.m. and the other twenty are fired at 2 a.m. All heaters are extinguished at 6 a.m. You have, therefore, two different groups each of twenty heaters.

Always record the time the first heater in the group was fired and extinguished. It may take an hour or even more before all heaters are fired (or extinguished) but it is assumed that they are fired and extinguished in the same order and therefore all the heaters of one group are in operation approximately the same time.

9. In case you use any other frost/freeze protection method, such as overhead sprinkling, flood irrigation, etc., please fill in the total cost of operating these protection systems for this particular night. Please prorate all costs to this particular grove.
10. During the frost/freeze protection activities your trucks had to pick up some equipment and automobiles were used to transport the personnel between the homes, offices, groves, etc. Please try to estimate the total mileage of the cars and trucks, prorated to this particular grove, even if they are not your vehicles.
11. The question is answered only if you have at this grove a control thermometer outside of the protected area which would record the true temperature at the grove (i.e. temperatures which would be obtained throughout the entire grove if it would be unprotected).
12. If there is any damage to fruit and/or trees as a result of frost/freeze which was not previously reported, then please fill out a damage report.
13. You may have decided not to take any protective action or limited action at no cost even if the temperature was predicted by NWS to be 28°F or less. You incurred no costs and you may have observed some damage to fruit and/or trees (see Question 12) or not. Circle as many reasons as might apply when you made your decision.

NIGHTLY FROST/FREEZE PROTECTION ACTIVITY REPORT

Please limit your answer to one grove only (see the instruction sheet for the definition of a "grove" as used in this report). Please answer the following questions only if a fruit frost bulletin by NWS predicted the lowest temperatures to be 28°F or less for the zone in which this grove is located or you had taken any frost/freeze protection during which you incurred costs regardless of predicted temperatures.

1. Your own grove name: _____ grove I.D. number: _____
2. Date of frost/freeze Month: _____ Day: _____
3. Which of the NWS forecasts influenced you to initiate some form of frost/freeze protection? 1 10:15 a.m.
2 4:15 p.m.
3 10:15 p.m.
[CIRCLE ONE NUMBER]

4. On a scale of one to ten, how much confidence do you have in the NWS forecast identified in Question 3?
- | | | |
|----------------------|---------------|---------------------|
| [CIRCLE ONE NUMBER] | no confidence | absolute confidence |
| 1 2 3 4 5 6 7 8 9 10 | | |

5. On this night, did you take any action which incurred costs (including calling in laborers, paying someone extra to check the equipment, starting wind machines, firing heaters, etc.)?
- 1 Yes
2 No...GO TO QUESTION 12

6. Labor costs associated with this night's frost/freeze protective action, prorated to this grove:
- 1 Total direct wages of laborers called in \$
2 Extra direct wages of other personnel to supervise, to monitor weather, check or operate equipment, etc. \$

7. Wind machines:

	Number of Machines	Fuel Type	Fuel Consumption Rate*	Time (hours and minutes)	
				On	Off
Group 1					
Group 2					
Group 3					

*gasoline.....gallons/hour
diesel.....gallons/hour
propane.....pounds/hour
electricity...kilowatts/hour

8. Heaters:
- | | Number of Heaters | Fuel Type | Fuel Consumption Rate* | Time (hours and minutes) | |
|---------|-------------------|-----------|------------------------|--------------------------|--------------|
| | | | | Fired | Extinguished |
| Group 1 | | | | | |
| Group 2 | | | | | |
| Group 3 | | | | | |
| Group 4 | | | | | |
| Group 5 | | | | | |
| Group 6 | | | | | |
- *diesel.....gallons/hour
propane.....pounds/hour
9. Operating costs of any other used frost/freeze protection method: \$ _____
10. Total approximate mileage incurred during frost/freeze protection travel, prorated to this grove: . . . Trucks: _____ miles
Automobile _____ miles
11. Minimum temperature recorded on the control thermometer for this grove: °F
12. Was there observed any damage to fruit and/or trees not previously reported? 1 Yes...DO NOT FORGET TO FILL OUT A DAMAGE REPORT
2 No
13. If you took no action which incurred costs what were the reasons for not taking it?
- 1 Weather conditions did not seem to warrant it
 - 2 Market conditions
 - 3 Anticipated protection costs too high
 - 4 Frost previously damaged
 - 5 Started too late—not enough time
 - 6 Took limited action. No additional expense incurred (alerting laborers, having checked equipment at no additional cost, etc.)
 - 7 Other reason; PLEASE EXPLAIN _____

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INSTRUCTIONS FOR DAMAGE REPORT

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When any damage to fruit and/or trees is observed then fill out a damage report. Please limit the answers for one grove to one report. If you observed damage in several of your groves which are part of the study then fill out several reports.

1. The grove identification and grove number are identical to those in your nightly reports and the grove background report.
2. The date when you fill out the damage report.
3. The damage due to frost/freeze can usually be determined only several days after the night when it actually happened. Fill in the date of the frost/freeze (could be one night or several nights) which resulted in the damage to fruit and/or trees in this grove.
4. If there is damage to fruit then fill out Questions 5 to 8. If there is damage to trees, then fill out Questions 5 to 8 and 9 to 11.
- 5-6. Answers to these questions would indicate if the damages due to frost/freeze changed your marketing plans.
- 7-8. The approximate loss of fruit could best be determined if you specify your estimates of yield from this grove in boxes per acre (if you produce for the fresh fruit market) or in lbs-concentrate per acre (if you produce for the processed fruit market) before the damage (i.e. the yield which would be achieved if the grove would not have been damaged) and after the damage to this grove.
9. Circle yes if there is any damage to the trees.
10. When trees in the grove are damaged then, depending on the severity of the damage, part of the next year or even part of the next several years' crop could be lost. Estimate the number of years before this grove would return to the full production.
11. Only certain sections of a grove may be damaged. Estimate the percentage of grove which was damaged.
12. Please enter any other comments you may have which would be helpful in the evaluation of damages.



DAMAGE REPORT

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- If you have any questions, call your county extension agent.***

APPENDIX C
DATA FORMS PACKAGE
(1977-78)

Since the cooperating county extension agents requested a larger role in administering the data collection forms in 1977-78, no data forms packages were sent to the growers themselves. Instead, copies of the forms included here were sent to the county agents, who either disbursed them to the growers personally or administered them over the telephone. Instructions for completing the forms remained approximately the same as the instructions given in the previous season, although in the 1977-78 season the agents were better able to ensure that the instructions were followed by the grower. The forms package sent to the agents late in 1977 included:

1. a Grove Background Report Update, to be filled out at the start of the frost season,
2. a Nightly Frost/Freeze Protection Activity Report, to be completed if the NWS frost bulletin predicted temperatures of 28°F or less, or if any action was taken by a grower,
3. a Nightly Report of Frost/Freeze Protection Costs, to be filled out whenever costs were incurred in a grove, and
4. A Damage Report, to be filled out at the end of the season if the grove experienced any damage during the season.



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Grove I.D.

GROVE BACKGROUND REPORT UPDATE '77-'78

1. What is the expected yield for this grove for the '77-'78
(Please give answer in boxes per acre.)

_____ boxes

2. What are your current marketing plans for this fruit? (Please
circle one answer.)

- 1 Fresh
2 Processed
3 Undecided

3. What is your expected month of harvest for the fruit? (Please
circle one answer.)

- | | |
|------------|-------------|
| 1 January | 7 July |
| 2 February | 8 August |
| 3 March | 9 September |
| 4 April | 10 October |
| 5 May | 11 November |
| 6 June | 12 December |

4. If you have added or removed any frost protection equipment since
last season, please describe below. (For heaters or wind machines,
please give type, number, type of fuel, and fuel consumption rate.)

5. If you noticed any errors in the first section of your season-end
report, please list them below so that we may correct our records.



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NIGHTLY FROST/FREEZE PROTECTION ACTIVITY REPORT

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This form can be filled out for several groves at once, if different answers to the questions are not required. Please start a new form whenever necessary.

1. Grove Identification number(s) _____
2. Date of frost/freeze _____
3. Which of the NWS forecasts influenced the grower's decisions on this night?

1 10:15 a.m.

2 4:15 p.m.

3 10:15 p.m.

CIRCLE ONE NUMBER

4. On a scale of one to ten, how much confidence does the grower have in the NWS forecast identified in Question 3?

no

confidence

1 2 3 4 5 6 7 8 9 10

absolute

confidence

CIRCLE ONE NUMBER

5. On the night identified above, did the grower take any action in any of his groves?

1 Yes ... (Indicate grove I.D. numbers) _____

2 No

If action was taken, please fill out protection cost forms for relevant groves.

6. On the night identified above, did the grower experience any damage to fruit or trees not previously reported?

1 Yes ... (Indicate grove I.D. numbers) _____

2 No

If damage was experienced, please fill out damage reports for affected groves.

7. If no action was taken which incurred costs, what were the reasons for not taking it?

1 Weather conditions did not seem to warrant it

2 Market conditions

3 Anticipated protection costs too high

4 Frost previously damaged

5 Started too late - not enough time

6 Took limited action. No additional expense incurred (alerting laborers, having equipment checked at no additional cost, etc.)

7 Forecasted minimum temperature not cold enough

8 Other reason; PLEASE EXPLAIN _____

NIGHTLY REPORT OF FROST/FREEZE PROTECTION COSTS

Please fill out a separate form for each grove in which some action was taken.

1. Date of frost/freeze: _____
2. Labor costs associated with this night's frost/freeze protective action, prorated to this grove:
 - 1 Total direct wages of laborers called in \$ _____
 - 2 Extra direct wages of other personnel to supervise, to monitor weather, check or operate equipment, etc. \$ _____

3. Wind machines

	Number of Machines	Fuel Type	Fuel Consumption Rate	Hours of Operation
Group 1				
Group 2				
Group 3				

Fuel codes:

- 1 #2 Diesel
 - 2 Gasoline
 - 3 Liquid Propane
 - 4 Butane
 - 5 Other (please specify)
- _____

4. Heaters

	Number of Heaters	Fuel Type	Fuel Consumption Rate	Hours of Operation
Group 1				
Group 2				
Group 3				

Fuel Codes:

- 1 #2 Diesel
 - 2 Gasoline
 - 3 Liquid Propane
 - 4 Butane
 - 5 Other (please specify)
- _____

5. Operating costs of any other frost protection method: \$ _____

6. Total approximate mileage incurred during frost/freeze protection travel, prorated to this grove:

Trucks _____ miles

Automobile _____ miles

7. Minimum temperature recorded on the control thermometer for this grove (if applicable)

_____ °F

DAMAGE REPORT - Q

1. Date of frost/freeze damage
(Use date associated with a.m. hours of the cold night)
2. In this grove, was there any damage to the fruit on the night indicated?
3. How did you intend to market the fruit before the damage?
4. How do you intend to market the fruit now?
5. When did you (or do you intend to) harvest your fruit?
6. How would you estimate the yield before the damage?
(indicate choice of units)
7. How would you estimate the yield after the damage?
(indicate choice of units)
8. Was there any damage to the trees on the night indicated?
9. If there was tree damage, in how many years do you expect full production to resume?
10. How much of a reduction in total production for the grove do you expect next year?
11. What is the approximate percentage of trees that were damaged?
12. Would you wish to make any other comment concerning damage to this grove?

is side for county extension agent's records



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DAMAGE REPORT-A

I.D No.

Date _____

Please limit your answers to one grove only.

1. Month: _____ Day: _____

2. 1 Yes
2 No ... GO TO QUESTION 8

3. 1 Fresh
2 Processed

4. 1 Fresh
2 Processed

5. _____

6. _____ boxes per acre, or per grove
_____ lbs-solids per box

7. _____ boxes per acre, or per grove
_____ lbs-solids per box

8. 1 Yes
2 No ... GO TO QUESTION 12

9. _____

10. _____

11. _____

12. _____

APPENDIX D
STATISTICAL RESULTS OF FORECAST VERIFICATION

The following is a detailed summary of the forecast verification results for forecast zones 9, 11, 13, 14 and 15. The reader should refer to Section 4 of this report for a detailed discussion of the verification methodology and for a critical assessment of the results summarized below.

The results for each zone are given in the following sequence. First, the number of raw observations, and mean and variance of these observations, is given for each of the two frost seasons. (A "raw observation" corresponds to a single unadjusted difference between a forecast midpoint and the actual observed minimum temperature at a particular thermometer on a particular night.) Next, the results of the two-year regression based on the model:

$$T_{ijk} = F_{jk} + u_i + e_{ijk}$$

are given. In the model, T is the actual minimum temperature at a particular thermometer, F is the zone forecast, u is the thermometer shift factor, and e is a random error term. The subscripts i , j and k refer to thermometers, cold nights and zones, respectively. Following the regression results are the number of adjusted observations (differences based on forecasts adjusted to the particular thermometer by means of the estimated shift factors), and mean and variance of these observations. The mean adjusted difference is also known as the "bias" of the set of forecasts. The last section of the statistical results contains a summary of the statistical tests performed on the mean adjusted differences and on the variance of these observations.

Key to Terminology

- n number of observations (= number of thermometers x number of verification nights in a zone, minus any missing observations)
- d_{ij} difference between forecast in a zone and observation temperature at a given thermometer, on a given night
- $\bar{d}$ mean difference or seasonal bias ($= \frac{\sum d_{ij}}{n}$)
- s^2 seasonal sample variance of differences ($= \frac{\sum (d_{ij} - \bar{d})^2}{n-1}$)

Results for Zone 9

Raw data:	<u>Year 1</u>	<u>Year 2</u>
	$n = 256$	$n = 376$
	$\bar{d} = 2.06$	$\bar{d} = 3.17$
	$s^2 = 25.70$	$s^2 = 18.66$

Results of two-year regression:

<u>Thermometer</u>	<u>Coefficient</u>	<u>t-Statistic</u>	<u>Significant at 95 % Level?</u>
1	-2.53	-4.82	YES
2	-0.08	-0.14	NO
3	0.99	1.88	NO
4	2.29	4.36	YES
5	5.19	9.88	YES
6	5.34	10.17	YES
7	5.44	10.36	YES
8	5.13	9.76	YES

Adjusted differences:

Year 1Year 2

n = 256

n = 376

 $\bar{d} = .07$ $\bar{d} = -.56$ $s^2 = 14.85$ $s^2 = 12.36$

Statistical test on means:

1. Confidence level (probability of type 2 error) = .05
2. $t' = 2.103$
3. Critical point ≈ 2.25
4. t' is less than critical point, therefore, it is not possible to reject the null hypothesis. There has been no significant change in bias.

Statistical test on sample variances:

1. Null hypothesis $\sigma_1^2 = \sigma_2^2$; alternative hypothesis σ_1^2 is greater than σ_2^2
2. Confidence level (probability of type 2 error) = .05
3. $f = 1.20$
4. Critical point = 1.215
5. f is less than the critical point, therefore it is not possible to reject the null hypothesis in favor of the alternative hypothesis. However, since f is so close to the critical point, it is difficult to make an unambiguous conclusion about whether the variance has declined significantly.

Results for Zone 11

Raw data:

Year 1Year 2

n = 336

n = 385 (1 thermometer
with missing data) $\bar{d} = .36$ $\bar{d} = .73$ $s^2 = 22.57$ $s^2 = 22.39$

Results of two-year regression:

<u>Thermometer</u>	<u>Coefficient</u>	<u>t-Statistic</u>	<u>Significant at 95 % Level?</u>
1	- some missing data -		
2	-0.78	-1.06	NO
3	0.44	.60	NO
4	1.49	2.03	YES
5	.10	.13	NO
6	.63	.86	NO
7	-.46	-.63	NO
8	-.60	-.82	NO
9	.51	.69	NO
10	-1.40	-1.90	NO
11	3.27	4.44	YES
12	3.30	4.49	YES

Adjusted differences:

Year 1Year 2

n = 308

n = 385

 $\bar{d} = .39$ $\bar{d} = -.06$ $s^2 = 21.44$ $s^2 = 21.23$

(Thermometer 1 was eliminated due to missing observations in year 2.)

Statistical test on means:

1. Confidence level (probability of type 2 error) = .05
2. $t' = 1.28$
3. Critical point $\cong 2.25$
4. t' is less than critical point, therefore, it is not possible to reject the null hypothesis. There has been no significant change in bias.

Statistical test on sample variances:

1. Null hypothesis $\sigma_1^2 = \sigma_2^2$; alternative hypothesis σ_1^2 is greater than σ_2^2
2. Confidence level (probability of type 2 error) = .05
3. $f \cong 1.01$
4. Critical point = 1.208

5. f is less than the critical point, therefore it is not possible to reject the null hypothesis in favor of the alternative hypothesis. There has been no statistically significant decline in variance.

Results for Zone 13

Raw data:	<u>Year 1</u>	<u>Year 2</u>
	$n = 270$	$n = 414$
	$\bar{d} = 3.13$	$\bar{d} = 4.70$
	$s^2 = 6.05$	$s^2 = 8.92$

Results of two-year regression:

<u>Thermometer</u>	<u>Coefficient</u>	<u>t-Statistic</u>	<u>Significant at 95 % Level?</u>
1	-2.32	-2.79	YES
2	-1.97	-2.37	YES
3	-2.39	-2.88	YES
4	-2.63	-3.17	YES
5	-1.18	-1.42	NO
6	-.39	-.47	NO
7	-.03	-.03	NO
8	-.34	-.41	NO
9	-.11	-.13	NO
10	-3.00	-3.61	YES
11	-.53	-.63	NO
12	-.26	-.32	NO
13	.87	1.04	NO
14	4.32	5.19	YES
15	- some missing data -		
16	3.39	4.08	YES
17	2.74	3.29	YES
18	1.95	2.34	YES

Adjusted differences:	<u>Year 1</u>	<u>Year 2</u>
	$n = 255$	$n = 391$
	$\bar{d} = .731$	$\bar{d} = -.284$
	$s^2 = 9.24$	$s^2 = 17.14$

(Thermometer 15 was eliminated due to missing observations in year 2.)

Statistical test on means:

1. Confidence level (probability of type 2 error) = .05
2. $t' = 3.59$

3. Critical point $\cong 2.25$
4. t' is greater than critical point, therefore, the null hypothesis should be rejected. The evidence suggests that there has been a statistically significant change in bias. It is notable that the bias has also changed in sign as well as magnitude.

Statistical test on sample variances:

1. Null hypothesis $\sigma_1^2 = \sigma_2^2$; alternative hypothesis σ_1^2 is greater than σ_2^2
2. Confidence level (probability of type 2 error) = .05
3. $f = 1.85$
4. Critical point $\cong 1.22$
5. f' is greater than the critical point, therefore the null hypothesis must be rejected in favor of the alternative hypothesis. The evidence suggests that there has been a statistically significant increase in forecast error variance over the time period considered.

Results for Zone 14

Raw data:	<u>Year 1</u>	<u>Year 2</u>
	$n = 285$	$n = 374$ (2 thermometers with missing data)
	$\bar{d} = -.51$	$\bar{d} = -.14$
	$s^2 = 10.57$	$s^2 = 19.07$

Results of two-year regression:

<u>Thermometer</u>	<u>Coefficient</u>	<u>t-Statistic</u>	<u>Significant at 95 % Level?</u>
1	-3.15	-2.18	YES
2	1.36	.95	NO
3	.26	.18	NO
4	-2.96	-2.05	YES
5	-1.64	-1.13	NO
6	.61	.42	NO
7	-.34	-.23	NO
8	-.50	-.35	NO
9	1.55	1.08	NO
10	-.01	-.01	NO
11	-1.28	-.89	NO
12	.91	.63	NO

13	- some missing data -		
14	-.58	-.40	NO
15	1.58	1.10	NO
16	1.04	.72	NO
17	- some missing data -		
18	-1.23	-.85	NO
19	-1.01	-.70	NO

Adjusted differences:	<u>Year 1</u>	<u>Year 2</u>
	n = 255	n = 374
	$\bar{d} = .14$	$\bar{d} = -.17$
	$s^2 = 9.57$	$s^2 = 18.22$

(Thermometers 13 and 17 were eliminated due to missing observations in year 2.)

Statistical test on means:

1. Confidence level (probability of type 2 error) = .05
2. $t' = 1.04$
3. Critical point $\cong 2.25$
4. t' is less than critical point, therefore, it is not possible to reject the null hypothesis. There has been no significant change in bias.

Statistical test on sample variances:

1. Null hypothesis $\sigma_1^2 = \sigma_2^2$; alternative hypothesis σ_1^2 is greater than σ_2^2
2. Confidence level (probability of type 2 error) = .05
3. $f = 1.904$
4. Critical point = 1.223
5. f is greater than the critical point, therefore the null hypothesis must be rejected in favor of the alternative hypothesis. The evidence suggests that there has been a statistically significant increase in forecast error variance over the time period considered.

Results for Zone 15

Raw data:	<u>Year 1</u>	<u>Year 2</u>
	n = 196	n = 280
	$\bar{d} = -.265$	$\bar{d} = -1.44$
	$s^2 = 13.90$	$s^2 = 20.76$

Results of two-year regression:

<u>Thermometer</u>	<u>Coefficient</u>	<u>t-Statistic</u>	<u>Significant at 95 % Level?</u>
1	-1.35	-1.85	NO
2	1.03	1.41	NO
3	-.82	-1.12	NO
4	.24	.32	NO
5	-2.88	-3.94	YES
6	-2.65	-3.61	YES
7	-.44	-.60	NO
8	-.47	-.64	NO
9	-1.41	-1.93	NO
10	-.50	-.68	NO
11	-2.76	-3.77	YES
12	-1.53	-2.09	YES
13	-.74	-1.00	NO
14	.88	1.20	NO

Adjusted differences:

Year 1

Year 2

n = 196

n = 280

$\bar{d} = -.44$

$\bar{d} = .74$

$s_1^2 = 12.70$

$s_2^2 = 19.97$

Statistical test on means:

1. Confidence level (probability of type 2 error) = .05
2. $t' = 3.19$
3. Critical point $\cong 2.25$
4. t' is greater than critical point, therefore, the null hypothesis should be rejected. The evidence suggests that there has been a statistically significant change in bias. It is notable that the bias has also changed in sign as well as magnitude.

Statistical test on sample variances:

1. Null hypothesis $\sigma_1^2 = \sigma_2^2$; alternative hypothesis σ_1^2 is greater than σ_2^2
2. Confidence level (probability of type 2 error) = .05
3. $f = 1.57$

4. Critical point = 1.247
5. f is greater than the critical point, therefore the null hypothesis must be rejected in favor of the alternative hypothesis. The evidence suggests that there has been a statistically significant increase in forecast error variance over the time period considered.

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